Commission of the European Communities

industrial health and safety

Symposium 'Flammable dusts'

Luxembourg, 5.11.1981

Report

EUR 7908 DE, EN, FR

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CONTENTS

1 - Welcoming address.
P. LEMOINE 1

2 - Introduction to the conference on flammable dusts.
L. KOCH 7

3 - Current application of the Tremonia triggered barrier and its further development.
J. MICHELIS 11

4 - The Bergbau-Versuchsstrecke triggered barrier system with special reference to mobile applications.
E.W. SCHOLL 21

5 - Design, characteristics and pit trial of the Belgian triggered barrier.
P. BROWAEYS 29

6 - The Belgian triggered barrier system performance in a cul-de-sac test gallery.
P. GOFFART 47

7 - Current research on triggered barriers by the Health and Safety Executive.
D. RAE 81

8 - Explosion barriers and their current use in the Federal Republic of Germany.
H. JENDEREK 91

9 - Comparative study of flammable dust during deposition, deposited and raised into the air.
R. LIBERDA 97

10 - Activities in the field of multiple explosions
J. MEERBACH 119

11 - Multiple suppression system for triggered barriers.
M. FABER 129

12 - Prevention of weak dust explosions.
M. GILTAIRE and J. WINTER 137

13 - New operational developments in the use of dust-binding in the Federal Republic of Germany.
M. SCHNIER 163

14 - Future objectives in arresting explosions.
A.J. AINSWORTH 175

15 - Operational experience with triggered barriers within the U.K.
J.L. COLLINSON and R.T. PYE 179

16 - Short review of the conference of the Working Party on Flammable Dusts.
K. REINKE 193

Programme for the symposium on
"Flammable Dusts" on 5.11.1981 in Luxembourg

9.30^h Chairman: R.B. DUNN

1.	P. LEMOINE	Welcoming address	
2.	L. KOCH	Introduction	
3.	J. MICHELIS	Operational status of the "Tremonia" triggered barrier and its further development. Doc. No.	5022/81
4.	E.W. SCHOLL	The triggered barrier of the "Bergbauversuchsstrecke", particularly in respect of mobile applications. Doc. No.	5462/81
5.	P. BROWAEYS	Design, characteristics and technological underground testing of the Belgian triggered barrier. Doc. No.	5493/81
6.	P. GOFFART	The Belgian triggered barrier system - performance on the test rig and in stone and coal development drivages. Doc. No.	5494/81
7.	D. RAE	Current research on triggered barriers by the Health and Safety Executive. Doc. No.	4280/81
8.	H. JENDEREK	Explosion barriers and their use today in the Federal Republic of Germany. Doc. No.	5497/81
9.	DISCUSSION		

12.30 - 14.30^h Break

Chairman: J. VANDERPUTTE

10.	R. LIBERDA	Comparative study of flammable dusts - behaviour during settling, at rest and during raising into the air. Doc. No.	5023/81
11.	H. MEERBACH & M. FABER	Activities relating to multiple explosions. Doc. No.	5021/81
12.	M. GILTAIRE & J. WINTER	Control of weak coal-dust explosions. Doc. No.	5024/81
13.	M. SCHNIER	New operational developments in the use of dust binding in the Federal Republic of Germany. Doc. No.	3488/81
14.	A.J.AINSWORTH	Future objectives in arresting explosions. Doc. No.	4281/81
15.	FILM	Water troughs against dust explosions.	
16.	J.L.COLLINSON	Operational experience with triggered water barriers in the U.K. Doc. No.	4282/81
17.	DISCUSSION		
18.	K. REINKE	Summary	
	END	around 17.00^h.	

Welcoming address

P. LEMOINE

Information meeting on flammable dusts.

Luxembourg, 5 November 1981.

Gentlemen,

This meeting is intended as a means of informing you of the progress of the work carried out by the European Commission and the Safety and Health Commission for the Mining and Other Extractive Industries on the prevention of dust explosions in mines. In this sector, the ECSC's aid to research and the Safety and Health Commission's own work have made it possible to develop activities over the past few years which we believe to be useful and regarded as valuable within the industry, and which are both interlinked and complementary to each other.

Nevertheless, a reproach which is often made and is probably justified, is that mine managers are not adequately informed of the aims and results of the work already carried out or planned for the future. Although the dissemination of information is one of the European Commission's constant concerns there is still room for much effort to make information simple and effective and to propagate it rapidly.

Today, we are adopting a relatively modest approach, consisting in supplying information limited to a very specific subject to a group of technical experts from mining practice.

The subject which has been selected is the prevention of dust explosions in mines.

It is unfortunately still a topical subject and, in spite of the progress made so far, which we shall learn of in the course of the day, one of major concern to those responsible for mine safety. It was in fact not at all difficult to find people to inform you about work currently being carried out - so great is the desire in every coalmining country of the Community to prevent this kind of accident risk.

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Research into the prevention of dust explosions has always been carried out in mining countries and close contacts have been organized regularly between testing centres. There is no need for me to give you a historical account on this point, or to recapitulate the major mining disasters of the start of the century.

In 1962, however, two serious dust explosions occurred in rapid succession and alerted the industry: these were the Luisenthal disaster of February 1962 and the Sachsen Mine disaster of March 1962. The two accidents tragically drew attention to the fact that in modern mines, where safety is a well-established principle, safety systems, and especially stone-dust explosion barriers, can prove ineffective. At Luisenthal, an incredibly violent explosion developed in a network of workings and roadways where hydraulic stowing was being carried out, and which were therefore very humid. At Sachsen, the explosion started and spread in roadways with very large sections.

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In 1962, the Safety and Health Commission had been in existence for barely five years and had instituted work in sectors selected mainly on the basis of the conclusions drawn from the Marcinelle disaster (1956). During that same period, ECSC research had started in the coal sector, with attention focused on the control of firedamp emission, in the field of safety, and on the prevention of pneumoconiosis in miners, in the social sector.

The disasters of 1962 therefore caused the Community to revise its projects and programmes.

The Safety and Health Commission accordingly set up a new working party, that on "Flammable Dusts", currently chaired by Mr Koch, who, I am sure, will give you a summary of this work.

In the wather of aid to reasearch, arrangements were made to subsidize research on the prevention of explosion risks.

Since the introduction of the Community research projects, a total of 23 contracts have been signed, representing a total aid of over 3 million ECU. It should be noted that the aid granted is only partial, amounting in general to 60 % of the research costs, and that the institutes have to obtain further financing for the remaining 40 %. The aid therefore has a multiplying effect.

Most work is conducted on a Community basis, i.e. after consultations between the institutes concerned, in order to avoid any duplication of effort and unnecessary outlays on equipment or tests. A large proportion of Community testing is therefore carried out full scale at the Tremonia Mine which, as you know, is remarkably well equipped.

The research projects which are selected are finally accepted by the European Commission after being examined by the representatives of industry and the governments concerned.

Since 1977, projects have been grouped into a first 5-year mines safety programme which has just been completed.

The European Commission had now drawn up a second programme which will probably run from 1982 on.

Explosion prevention, and the prevention of dust explosions in particular, has a firm place in this programme. This year, therefore, we will have the task of including in this programme projects aimed at improving prevention. I am sure that today's meeting will provide useful ideas along these lines.

In 1962, the initial research proposals first dealt with research into the effectiveness of explosion barriers in the context of modern mines, and work was concentrated on the use of water trough barriers adapted to roadways with large cross-sections, including roadways or roadways with special installations such as monorails.

At the same time, research into dust binding, for example by means of salt pastes or powders, led to the development of effective practical equipment.

Whilst this work was being carried out at the institutes, the Safety and Health Commission collected the findings thus obtained and disseminated them in the form of opinions or of proposals to governments in accordance with its terms of reference.

A new idea then originated, however; that of using a system which outpaced the explosion's shock wave to actuate the barrier.

The use of the light or radiation from the initial explosion were then considered, within the context of "triggered barriers".

This equipment could be used against explosions which are not suppressed adequately by the conventional explosion barriers, i.e. explosions which are too weak (but dangerous nevertheless) to actuate the barriers, as well as against violent explosions. Furthermore, it is thought that this type of protection can be employed at locations where conventional equipment is difficult or impossible to instal.

The work is difficult and not yet completed, and persons who are better qualified than myself will today discuss this question which is very important for the future organization of mining safety.

These, Gentlemen, are the points I wanted to make at the start of your working session. There are no doubt many others worth making, but I know that your time is precious.

On behalf of the Commission of the European Communities I would like to thank in particular,

- Mr Koch, Chairman of the Safety and Health Commission's Working Party on Flammable Dusts
- the meeting's chairmen, Mr Dunn, for the morning session, and Mr Mayné, for the afternoon session
- the general rapporteur, Mr Reinke, who will draw the conclusions from today's meeting
- all those speakers who have prepared for us a general review of their research work

and finally, last but not least, Mrs Schneider and Mr Wetekam, who have worked hard to ensure that this meeting will go well.

I declare the information meeting open and wish you much success in your work.

P. LEMOINE

Introduction to the conference on flammable dusts

L.KOCH

Ingénieur Général des Mines

With 13 talks and one film, the programme of the conference on flammable dusts is a full one. I will therefore be brief and give you a quick introduction to the Safety and Health Commission's Working Party on Flammable Dusts and the subjects covered by today's meeting.

The terms of reference given to the Working Party by the Safety and Health Commission are concerned with all aspects of the suppression of coal dust ignition in underground mines. I would like to give you details of the Working Party's work on the basis of the thirty or so documents which it has examined or prepared over the past ten years.

Six areas have come under study during this period:

- the memorandum on useful information for the study of coal dust explosions or firedamp ignitions in the mining industry has been reworked, revised and published by the Safety and Health Commission;

- dust neutralization using salt pastes, powders and flakes developed in the Federal Republic of Germany has been examined by the Working Party. It is the subject of an information report and recommendation;

- the technique of water-trough explosion barriers, which has also been perfected in Germany, has been discussed at length and forms the subject of a recommendation;

- research on triggered barriers has been conducted in most Community countries. The results have been compared with each other several times by the Working Party. I shall not go any further into this area since a large proportion of today's meeting will be devoted to it;

- the Working Party has looked into the organization of protection from coal dust explosions in the various coalmining countries of the Community;

- a number of meetings of the Working Party and of an ad hoc editorial committee have been devoted to completion of a recommendation on dust binding by means of linestone dust.

Outside the areas covered by these six topics, the Working Party has examined documents and assisted other Safety and Health Commission working parties in the preparation of draft directives on means of dust control during the use of winning and heading machines, as well as assisting in the formulation of an opinion on the disruptive effects of hygroscopic salts on electrical installations.

This brief report on the Working Party's activities shows that, in compliance with the Safety and Health Commission's instructions, the Working Party has always insisted on the preparation and publication of a recommendation or information report whenever any question has been examined in sufficient detail.

There are, however, areas in which publication would be premature, as in the case of triggered barriers. This conference was proposed by the Secretary of the Safety and Health Commission so that people who were responsible for mine management but whose contacts with research laboratories could only be sporadic could be informed of the latest results on triggered barriers.

Of the 13 talks to be given today, six are devoted to triggered barriers. The Federal Republic of Germany, Belgium and the United Kingdom will each present two papers, one on the results obtained by the testing centre and the other on the practical aspects of application underground. France has not carried out any research in this field recently.

The other talks you will hear today cannot be placed in a single category but do have one thing in common: they deal with research or questions currently under discussion.

The subjects of these talks are varied:

- explosion barriers and their current use in the Federal Republic of Germany,

- a French study on the behaviour of dust during deposition and dispersal,

- recent research on multiple explosions carried out at Tremonia,
- Cerchar will tell us about their tests on the suppression of weak explosions,
- we will hear about the latest developments in Germany on methods of dust winding by means of hygroscopic salts,
- future objectives arresting explosions in the United Kingdom.

Finally, last but not least, we shall see a film on the use of water troughs against coal dust explosions; this film was made on behalf of and financed by the Safety and Health Commission.

Summary of the paper entitled

Current Application of the Tremonia triggered barrier and its further development

for the Information Conference on

Flammable Dusts to be held in Luxembourg on 5.11.1981

Presented by

Dr J. Michelis

of the Versuchsgrubengesellschaft MBH

In the past few years, various types of triggered barrier system have been developed with generally the same aims in view in the West European coal-producing countries of Belgium, the Federal Republic of Germany, France and the United Kingdom. In the Federal Republic of Germany two systems have been perfected for general operation.

The Versuchsgrube Tremonia System consists of the triggering device, which functions on a thermoelectric basis, and the suppressant containers consisting of water troughs with ignition systems. Triggered barriers are always useful where conventional explosion barriers provide in adequate protection. In roughly 10 operations mainly carried out at the Saarbergwerke AG, some 4000 m of roadway have so far been driven under the protection of the Versuchsgrube Tremonia triggered barrier. In each case, a triggering device with a single sensor was used.

In order to allow the Versuchsgrube Tremonia triggered barrier to be used in broader applications, it has been further developed. The new triggering device, the DTS 80, consists of a central unit and a maximum of four external sensors which can be linked to this unit.

The main change in the DTS 80 unit is that no mechanical switching or plugging-in procedures are required for the test. An infra-red transmitter performs the switching operations optically. By using the latest electronic equipment, it has been possible to reduce the size of the central unit considerably so that the total weight has been halved from 150 kg to 75 kg. With the increase in the number of sensors from 1 to 4, the resistance of the ignition circuit has been increased from 40 to 80 ohms. A maximum of 80 water troughs with 80 ignition systems can now be installed, thus providing the triggered barrier with a much wider field of application.

Although the basic studies with the Versuchsgrube Tremonia triggered barrier can be regarded as concluded, this explosion barrier continues to be used in tests at Versuchsgrube Tremonia. Information has thus been obtained on its use in roadways with large cross-sections (of about 20 m^2). New information has also been drawn from tests in coal dust explosions with approach distances of 180 m. The strong pressure wave preceding the explosion influenced the operation of the triggered barrier in a hitherto unobserved manner. It is necessary for further studies to be carried out on the subject.

Current Application of the Tremonia triggered barrier and its further development

Paper for the Information Conference on

Flammable Dusts to be held in Luxembourg on 5.11.1981

Presented by

Dr J. Michelis

of the Versuchsgrubengesellschaft MBH

The development of triggered barriers providing protection from explosions in underground coalmines has resulted in two different systems in the Federal Republic of Germany. Both Bergbau-Versuchsstrecke and Versuchsgrubengesellschaft mbH have designed a barrier system ready for practical operation. Although the basic structure of a triggered barrier is the same in all systems, triggered barriers can vary from each other considerables in the individual elements. The structure, mode of operation and scope of application of the Bergbau-Versuchsstrecke system will be described in Mr Scholl's paper.

The Versuchsgrube Tremonia triggered barrier system, which is based on the use of water troughs in the middle of which ignition systems are installed, was developed mainly for use in roadways. It was planned from the very beginning as a barrier providing supplementary protection from explosions in particularly critical working areas. It also had to meet the requirement of being equally effective in all kinds of explosions, as far as possible. The West German coalmining industry has excellent explosion suppression equipment in the form of water trough barriers - and in particular the wide-action water trough barriers. Nevertheless, these types of barrier can only be used in specific minimum lengths of roadway and certain construction regulations have to be adhered to. Since it takes up much less space (80 l/m^2) than a concentrated water trough barrier (200 l/m^2), the Tremonia triggered barrier can be used in working areas where adequate protection from explosions cannot normally be provided.

Examples of such working areas are:

- conventional roadway drivages with high methane emission
- mechanized roadway drivages with full cut or selective heading machines
- T junctions
- highly critical working areas such as:
  - roadway junctions (in particular points of origin of ventilation districts)
  - material transfer points
  - bunkers
  - central coal-loading stations
  - special connecting roads.

The Tremonia triggered barrier has been in practical operation since 1974. Since this type of barrier was not given official approval until 1981, the intervening eight years must be regarded as a trial period. From 1974 to the end of 1980, the triggered barrier was used in eight working areas, mostly at Saarbergwerke AG, where the barrier provided protection for the drivage of some 4 000 m of roadway. The operation of the barrier at Ruhrkohle AG has so far been on a trial basis only.

Since the current version of the system has only one detector, it has so far only been possible to use it where there was a risk of explosion from one direction only. Roadway drivages have therefore been the main areas of application.

In order to allow the Tremonia triggered barrier to be used more widely, the DTS 74/2-S unit has been further developed. The new DTS 80 version contains a large number of improvements which practical experience with the DTS 74/2 had shown to be useful and necessary.

The DTS 80 triggering device consists of a central unit to which a maximum of four external sensors can be connected. The sensors function according to the thermoelectrical principle and have proved successful in over ten years of operation.

The central unit consists of three enclosures which are connected to each other.

The upper section, an 'intrinsically safe' enclosure, serves as the connecting box for one-four sensors. It also contains the connection points for the signalling circuits to the underground and surface stations.

The middle section, a 'flame-proof enclosure', houses all the electrical and electronic components, some of which I shall list without going into detail about their mode of operation:

- a 12 V, 9.5 Ah battery for emergency power
- a mains unit (charging set)
- ignition power production and storage unit (ignition capacitor)
- triggering booster
- power supply for the external sensors
- monitoring device for
  - evaluation of the sensor signal (test)
  - ignition voltage (capacitor)
  - ignition circuit (resistor)
  - battery (excess voltage - gas emission)
- signal contacts.

The 'flame-proof enclosure' is equipped with a panel of three instrument indicators, only two of which are used (one for monitoring the operation device's and one for switching sequences).

The indicator monitoring operation contains a panel of 17 light-emitting diodes which provide detailed information on the operation of the 1 - 4 sensors and other monitoring instruments for the central unit underground.

In contrast to this panel of lights indicating internal functions to the external observer, the second indicator shows switching sequences resulting from signals from the exterior (transmitter) to the interior (receiver).

The receiver behind this panel, which carries out switching sequences optically with the aid of lamps or modulated light (infra-red), is provided for the testing procedure between the sensors and the central unit. This is an elegant alternative to the use of external mechanical switches and plug connections.

Contrary to the testing procedure for the DTS 74/2 triggering unit, the ignition line of the DTS 80 triggering unit does not have to be separated externally. The intrinsically safe battery-powered infra-red transmitter (a manual unit the size of a cigarette packet) transmits coded infra-red signals through the panel to the receiver in the central unit. The ignition line leading to the ignition systems in the water troughs is thus switched over, via a relay, to an internal signal-storing testing device so that the hot water test can be carried out. After the testing sequence, the infra-red transmitter switches the ignition line over again to make the triggered barrier operational again. These functional sequences are indicated by the light-emitting diode panel, as already mentioned. The maximum ignition circuit resistance has been increased from 40 Ω to 80 Ω. It is therefore possible to install a maximum of 80 ignition systems, i.e. 80 water troughs. The actual resistance reading of the barriers is continuously monitored for deviations from the set value.

The lower section of the central unit, consisting of an 'increased safety' enclosure, contains the connections for the mains cable (220 V or 500 V), ignition cable and cables for the underground external visual or acoustic warning signal. It also houses the isolator terminals for switching off the unit, mains supply and battery connection.

Apart from the further development of the triggering device, it was also necessary to design new external sensors. Since the sensors had to be separated from the central unit and suspended over the underground roadways, the sensors had to be provided with a means of pre-amplifying the thermoelectric signal so that it could be transmitted over long distances to the central unit by an intrinsically safe system. Because of the various ways in which the sensor could be suspended, the protective cap for the thermoelectric elements had to be redesigned. The thermoelectric elements themselves are monitored for breakage and the sensor cables monitored for fractures and short circuits.

The redesign of the triggering unit resulted in a reduction of its overall weight from about 150 kg (DTS 74/2) to about 75 kg (DTS 80).

Although the basic studies of the applications of the Versuchsgrube Tremonia triggered barrier system, which were carried out under two research projects sponsored by the Commission of the European Communities, can be regarded as having been completed, the triggered barrier is still included in the current test programme.

As a result, general information on the dispersal of water in large roadway cross-sections has been obtained. An explosion gallery with a clear cross-section of about 20 m^2 is being prepared at the Versuchsgrube Tremonia to allow studies to be carried out in the type of cross-section commonly found in West German, coalmines nowadays. Unfortunately the gallery is not yet available for explosion tests and therefore tests have had to be restricted to those in which the triggered barrier is not ignited by the influence of explosions. It is not possible to draw direct conclusions from the water dispersal processes observed in such tests for cases involving explosions, but the water dispersal occurring within a period of about 400 to 500 ms in this "static" process has already proved adequate. This result should be improved considerably when the dynamic effects of an explosion's wind pressure are added.

In 1980, Versuchsgrube Tremonia and Bergbauversuchsstrecke triggered barriers were tested in the Versuchsgrube explosion gallery network in explosions with long approach distances. There, the approach distance to the barrier's location was 180 m compared with the previous maximum distance of about 160 m for explosion barriers. This relatively short extension of the approach zone to the barrier's location, however, provided valuable information on the use of triggered barriers.

In the case of the Versuchsgrube Tremonia triggered barrier system, the advanced pressure waves caused the water to be distributed too early in many cases, instead of by the ignition systems in the water troughs, since the explosion flame had not yet reached the sensor at that stage. Although the explosions were suppressed adequately in such cases, the barriers were less effective than the conventional concentrated water trough barriers because they contained 2.5 times less water.

In the case of the Bergbau-Versuchsstrecke triggered barrier system, the valve heads were twisted out of position during the explosions despite the use of protective caps. This prevented the barrier from functioning and therefore suppressing the explosions. More stable protective caps are to be used and the valve heads, including the nozzles, are to be secured to allow the barrier to function in this type of explosion,too. Suppression tests have yet to be carried out.

The range of problems involved in the operation of explosion barriers in explosions with long approach distances appears to be greater than initially assumed, and consequently more studies are necessary.

The ignition systems for the water troughs of the Tremonia triggered barrier are continuing to undergo long-term tests. At a testing location, ignition systems have been immersed in water under operating conditions since 1974. Single ignition systems are ignited at regular intervals, but so far none has failed to function.

In summary, as far as current and future applications of the Versuchsgrube Tremonia triggered barrier system are concerned, the information gathered since 1974 can be considered very useful and it has resulted in the further development of the triggering unit and sensors. With the triggered barrier, the coalmining industry has at its disposal a range of explosion suppression equipment capable of providing a valuable contribution to the safety of miners underground in critical circumstances also. It only remains to be hoped that appropriate use will be made of these means in practice.

Technical data of the DTS 80 triggering unit and sensor

1. Central unit:

Operating principle	: thermoelectric
Electrical connection	: 220 V or 500 V/50 Hz
Power consumption	: 5 W
Ignition capacitor	: 220 μF/350 V
Ignition impulse duration	: 2 ms
Ignition voltage	: 300 V
Maximum response temperature	: 45 K deviation from external temperature
Maximum ignition circuit resistance	: 80 Ω
Emergency power battery	: 12 V/9.5 Ah
Emergency power operating period	: 24 h
Testing current	: 0.2 mA
Type of protection	: Sch (d), Sch (e), Sch (i)
Signal contacts	: intrinsically safe and non-intrinsically safe
Dimensions of unit	: 700 mm x 400 mm x 175 mm
Weight	: approx. 75 kg.

2. Sensor:

Thermoelectric element	: Pt – Pt/Rh
Supply voltage	: 12 V
Connection cable	: 4 conductors with sheating type Liy Cy 4 x 1.5 (blue)
Type of protection	: Sch (i)
Dimensions of unit	: length 390 mm; diameter 70 mm
Weight	: approx. 5 kg.

The Bergbau-Versuchsstrecke triggered barrier system with special reference to mobile applications

Dr E.W. Scholl
Bergbau-Versuchsstrecke

In the period from 1963 to 1965, the Bergbau-Versuchsstrecke was assigned the task protecting firedamp drainage units from explosion. Lightning is a potential ignition source for these units at the surface since it can strike the exhaust pipe and cause fires, as has frequently occurred in the past. If conditions are such that the fire develops into an explosion, the latter is prevented from spreading to underground areas by mechanical flame traps. To extinguish a fire at the mouth of the exhaust pipe whilst the drainage unit is in operation, an automatic fire extinguishing system was installed. Various suppressants were tested, e.g. carbon dioxide, halon and dry powder, and it was found that only 5 kg of sodium bicarbonate powder were sufficient to extinguish a methane flare fire with a flow rate of 6000 - 7000 m^3/h.

The effectiveness of this powder and the small quantity of suppressant required gave rise to the idea of containing methane explosions in a pipe of 300 mm diameter and 70 m length without a mechanical flame trap by controlled injection of sodium bicarbonate. The explosion is detected by a visual flame detector which detonates charges to open the valves of suppressant containers within the space of milliseconds. The suppressant in the containers is under a pressure of 60 bars from a propellant gas (N_2) and is sprayed into the pipe very quickly when released. Explosions with speeds of up to 1000m/s have been suppressed in this way. - The name "automatic suppressant barrier" was given to this equipment, which has operated very successfully for years as an explosion protection device for firedamp drainage units. The barrier later became known as the "triggered barrier" in the context of underground mining.

Water trough and stone dust barriers are passive barriers. The suppressant has to be dispersed by the pressure of the explosion. The flame following the pressure wave then enters the cloud of dispersed suppressant and is subsequently extinguished. The effectiveness of these barriers, however, is limited. They can fail when insufficient pressure is created in the explosion's approach (e.g. in deflagrations of methane roof layers) or when the explosion becomes too strong.

In contrast to conventional explosion barriers, the triggered barrier is an active barrier whose suppressant is dispersed by an independent energy source. Its operation does not depend on the explosion pressure and it can therefore contain explosions with hardly any pressure. The positive results in the suppression of methane explosions in the 300 mm diameter pipe gave rise to a study of the suitability of the triggered barrier as an explosion barrier for underground mining also. Two pipes with diameters of 1400 mm and 2500 mm (corresponding to cross-sections of 1.5 m^2 and 5 m^2 respectively) with lengths of 40 m and 140 m respectively were therefore installed at the Bergbau-Versuchsstrecke. The pipes were used to test the triggered barrier's effectiveness in suppressing all types of explosions occurring in mines, such as methane, coal-dust and methane/coal-dust explosions, and deflagrations of methane roof layers.

The quantity of suppressant was reduced by altering the extinguishing system, e.g. continual improvements in the detector unit, more effective suppressant powder, an increase in the pressure of the propellant gas in the suppressant containers to 120 bars, and in increase in the suppressant dispersal rate following the use of containers with two valve outlets. The number of suppressant containers was also reduced by using larger ones with a content of 12.3 l. Furthermore, the distance between the flame detector and the triggered barrier was varied according to the type of explosion to obtain the best approach time for the dispersal of the suppressant. The approach time is the period in which the suppressant powder which has been released by the detector has to be dispersed at the barrier so that, when the flame arrives at the triggered barrier, these is enough powder spread over the entire cross-section of the pipe.

The main result of the tests was that all types of mine explosions with speeds of up to 400 m/s were suppressed with a powder containing ammonium phosphate.

The testing of the BVS triggered barrier system continued with underground tests at the Versuchsgrube Tremonia in roadways with even larger cross-section. In line with its possibilities of application, the barrier was tested in two straight cul-de-sacs: one with an arched cross-section of 8 m^2 and one with a rectangular cross-section of 7 m^2, as well as at a T-junction formed by these two roadways. The suppressant containers were positioned either next to the wall in two rows opposite each other, or next to centre props in two rows half-way up between the roof and the floor. They were pointed across the line of the roadway, and the distance between the detector and suppressant containers was approximately 40 m.

The effectiveness of the triggered barrier already established in tests at the surface was also confirmed underground by these explosion tests. Methane and coal-dust explosions, as well as deflagrations of methane roof layers with flame speeds of up to 500 m/s, were suppressed by a specific quantity of powder of 20 kg/m^2 of ammonium phosphate.

An explosion barrier used underground, however, must not only have an effective extinguishing system but also a detector capable of triggering off this system at the right moment. An ultraviolet detector functioning on a highly selective basis was used for this purpose. It responds to open flames and is insensitive to artificial light, e.g. mine lighting. This detector is available in flameproof design. The suppressant containers are also flameproof and the detonation valves are equipped with the flameproof enclosures used for the extinguishing equipment on underground firedamp exhaust units.

Triggered barriers may be used in highly dangerous working areas, such as at T-junctions and in roadways drivages. They are also suitable dor sealing off ventilation districts where the prescribed distances are not maintained. An advantage of this type of barrier in the latter context is that the suppressant containers are small and can therefore be installed easily, for example, between the support arches at roadway walls, without causing any substantial reduction in the clearance of the roadways or tracks.

Furthermore, when mounted on a mine car, it can serve as a mobile barrier in critical situations, e.g. for protecting the rescue service in mine fires.

Finally, power loaders and heading machines, which produce sparks likely to cause fires or explosions, can be equipped with detectors and suppressant containers to provide an effective barrier against explosions.

After several ignitions had been caused by selective heading machines, it was decided to carry out extinguishing tests with a modified triggered barrier on a selective heading in a 20 m^2 arched roadway.

A detector was installed on each side of the cutting boom, pointing towards the heading face, to detect flames. The suppressant powder was dispersed through fan-shaped installed radially on a ring around the boom, in front of the headlights. The suppressant containers were also installed near the headlights.

Homogeneous methane/air mixtures (9 % vol., 12 % vol. 30 m^3, 70 m^3) were ignited by electric sparks between the end of the cutting head and the heading face. The ignition location was varied by changing the position of the boom. The following five ignition locations were selected: the middle of the heading face, the floor next to the left wall, the roof over the middle of the roadway, the roof next to the right wall and the floor in the middle of the roadway. The ignition locations covered all the relevant possibilities for explosions and the suppression process.

Non-homogeneous methane roof layers of 6 m length and up to 1.5 m thick were ignited in the transitional zone between the air and methane roof layers, where an ignitable methane/air mixture had formed as a result of intermixing.

To simulate the emission of large quantities of methane, as may occur for example during a rock burst, a gas fire was ignited with 150 m^3/h of pure methane.

The explosions of homogeneous methane/air mixtures, deflagrations of methane roof layers and methane fires were extinguished by six suppressant containers, each filled with 8 kg of suppressant powder. The temperatures measured near the driver's seat reached approx. 60 C for short periods only.

A further application for the triggered barrier is as a mobile unit in critical rescue service operations. This mobile barrier, a prototype of which has already been built, consists of an ultraviolet detector, an evaluation unit, an emergency power battery and 32 suppressant containers. The barrier is mounted on two frames which can be connected easily. The frames are designed so that they can be transported either on normal pallet trucks or by overhead monorail. The frames have the following dimensions: length: 3.17 m, width: 0.84 m and height: 1.8 m. Each frame weighs approximately 1500 kg.

The barrier is equipped with 32 suppressant containers, half of which are installed on either side of the frame, and groups of 8 containers are each linked by one ignition circuit.

The fast-spraying extinguishing equipment mainly consists of a 12.3 l suppressant container, 2 detonating, quick-opening valves, 2 flameproof enclosures, 2 nozzles and suppressant powder.

The evaluation unit monitors itself for the following faults: failure of the detector, power failure in the entire installation and a break in the switched-on ignition circuits.

The mobile triggered barrier is designed for roadways of up to 20 m^2 cross-section.

When it is required, the barrier is taken to the location as quickly as possible, installed as near to the middle of the roadway cross-section as possible and the detector is positioned about 40 m from the barrier, between the possible ignition source and the barrier. The detector should be positioned, if possible, under the roof or next to the roadway wall, so that the surface which is sensitive to radiation is perpendicular to the line of the roadway, i.e. pointing to the floor or the opposite wall.

The fan nozzles for dispersing the suppressant are screwed on at the place of use. They are positioned perpendicular to the line of the roadway with the lower nozzle of a container next to the valve outlet pointing towards the roadway walls and the upper nozzle pointing to the roof at the end of a 90° - curved pipe.

This prototype mobile triggered barrier has been stationed in the central support warehouse of a group of collieries. The barrier has been demonstrated to supervisors of the mines rescue services and a limited group of rescue team leaders has been instructed in the use of the barrier. During a mines rescue exercise, a test was carried out to establish how the barrier could be transported and handled under practical underground conditions.

On completion of the trial phase with the first prototype mobile triggered barrier, changes which had become necessary and desirable were carried out. As a result, the barrier has had to be generally redesigned and therefore a second prototype is currently under construction.

The new mobile triggered barrier will not only have much smaller clearance dimensions (a reduction in height and width) than the former prototype, but will also accommodate 50 suppressant containers without its length having been altered. This increase in the number of containers should be considered in the context of a multiple ignition system which makes it possible for the barrier to detect and extinguish a second explosion after being actuated by a first explosion. A special automatic system ensures that after it has responded a first time the barrier automatically becomes operational again after a space of time which varies according to the circumstances. Furthermore, special holders with which the barrier can be transported by overhead monorail at any angle to the longitudinal axis, and non-rotating high-pressure sockets have been developed for the extinguishing nozzles to eliminate the lengthy procedure of sereving on the nozzles at the place of use.

This report is intended as a review of the development of the BVS triggered barrier system, its basic design and areas of application in underground coal mines.

DESIGN, CHARACTERISTICS AND PIT TRIAL OF THE BELGIAN TRIGGERED BARRIER (P. BROWAEYS)

For over ten years work has been in progress on the development of triggered explosion barriers in the countries of the European Community which still have an active coalmining industry and in other countries where the matter is of interest, such as the United States of America and Poland.

The term "triggered barrier" is applied to any system designed to provide an automatic means of arresting explosions in mine roadways and comprising at least one explosion sensor whose function is to trigger the system together with the appliances initiated by the triggering device, which contain the suppressant material and the source of dispersion energy.

In principle, such a system must provide selective detection of the explosion to be suppressed and must be able to quench the flame within the length of roadway where it is installed irrespective of the strength of the blast.

Basic lines of approach adopted in the Belgian research

Conventional (non-triggered) barriers with tipping shelves of stone dust or frangible water troughs operate only if the blast reaching the barrier is sufficiently strong to disperse the suppressant. They are therefore unable to quench the flame of an incipient explosion in the immediate vicinity of the source of ignition.

A further point to be considered in relation to conventional barriers is that while the concentrated barrier does offer certain advantages, the wide - action barrier is a better means of ensuring general explosion protection in mine roadways.

From the outset, Belgian research into triggered barriers took account of the lessons learned in the work on conventional barriers and is to the best of our knowledge the only research which has produced a triggered system suitable for both wide-action and concentrated arrangements.

The greater effectiveness of a wide-action triggered barrier is apparent from the diagram in Figure 1. The position of the sensor D which is effective against the explosion in question has been marked, on the horizontal axis representing distance along the roadway to be protected, as have a concentrated disperser C (installed at the distance d from the sensor) and a wide-action disperser R.

If the times are plotted as ordinates and it is assumed that the flame front advances at constant speed, being represented by a straight line on the distance/time graph, it is clear that if there is to be any possibility of quenching the flame this oblique line must intersect the short vertical line representing the duration of dispersion in a concentrated barrier t_C, which never lasts more than a few tenths of a second. The same straight line, or any other oblique curve if the flame speed varies, necessarely intersects the band t_R x R which represents dispersion in a wide-action barrier, provided R is sufficiently long to be called a wide-action arrangement.

In trials of a concentrated barrier in a fire gallery, it is thus necessary to conduct the tests with different distances d between the sensor and the disperser and to produce explosions with different flame speeds in the barrier zone for each experimental value of d. The experiment is thus complicated and the results generally reveal gaps in the effectiveness of the barrier.

It is then no easy matter to take account of these results when considering the use of the concentrated barrier in practice.

No such difficulties arise with a system which can ensure dispersion over a considerable length of roadway as the distance d is no longer a necessary parameter of the trials or practical application.

A wide-action triggered barrier, e.g. a few tens of metres in length, could keep pace with the advance of heading faces, while it would still be possible to install fixed-position systems, whether conventional or triggered, further outbye.

The objective of keeping pace with the advance of a drivage face in order to suppress an explosion as close as possible to its most likely point of initiation involves certain operational constraints: the components of the triggered barrier must be easy to handle, compact and able to fit into the space available in the working area without impeding the work carried out; the system as a whole must have sufficient flexibility to adapt to requirements and to the configuration of underground workings in coal mines.

It will thus be readily understood that INIEX concentrated on the development of a triggered barrier system designed to be compatible with practical service requirements and effective in both concentrated and wide-action arrangements. As will be explained in due course, the system has a 'multipoint' detection facility which is sensitive but at the same time selective and can trigger dispersion throughout the entire protected zone irrespective of the direction in which the explosion is propagated, whether the latter has already built up to its full velocity or is still in its initial stages.

The Belgian water disperser

A salient feature of the system as a whole is the originality of its explosive dispersion and transmission components which make use of the rapidity of detonation.

These components are mainly located inside the explosive-operated suppressor units which use water as a suppressant and are connected in series to ensure its dispersion in the zone to be protected.

Such suppressor units are shown in Figure 2.

Description of a suppressor unit

The water container is a PVC sheat enclosing a foam cylinder 2 m in length and 22.5 cm in diameter. The foam used is an open-pore polyurethane foam of suitable porosity.

The water container weighs 4 kg and is horizontally suspended in a robust cradle of wire mesh (weighing 6 kg) and filled with 90 to 100 litres of water.

The cylindrical foam block is pierced by an axial opening in which a watertight conduit is inserted, enclosing a long explosive disperser and transmission system with two branches projecting from either end of the water container, their ends being fitted with quick-acting connectors so that they can be joined to link the suppressor units in series.

The system of each unit consits of:

- a 1.5 m length of permitted detonating fuse containing 11 g/m of penthrite, disposed centrally in the foam block to act as a source of dispersion energy;
- two lengths of low-energy initiation shock tube whose function is to ensure continuity, mainly in the two branches between each of the quick-acting connectors and the ends of the central detonating cord.

Minidetonators containing only a small amount of primary explosive ensure transmission of the detonation between the detonating cord and the initiation tube and at the contacts which are automatically established between branches when suppressor units are linked up by means of the quick-acting connectors.

Operation of the suppressor units

Because the suppressor units and hence the disperser and transmission systems incorporated in each unit are series-connected, the ignition resulting from an initiating impulse passes from one unit to another.
Figure 2 illustrates such a connection arrangement.

The connecting lines of initiation tube carry a weak detonation travelling almost inaudibly and with no destructive effect at 2000 m/s.

In each of the series of water containers, the gases from the detonating fuse expel the water through the open pores of the foam, which is not destroyed, so that the PVC sheat bursts open in all directions and the water is dispersed in the form of droplets.

The various dimensional characteristics of the water container and the force of the detonating fuse used as a source of energy are such that:

- the front of water droplets projected in all directions by the exploding cord travels at velocities of about 50 m/s, measured vertically downwards;
- about 50 litres of water from each suppressor unit are atomized, the rest of the water being expelled later and falling straight down from the unit as a deluge;
- in a plane perpendicular to the axis of a suppressor unit, a 9 m^2 bell-shaped blanket of atomized water droplets, whose crown coincides with the unit in question, is formed as shown in Figs 3 - 5 within 150 ms and persists for 500 ms after detonation of the cord;
- at a distance of 10 - 20 cm from a water container which is burst by the detonating fuse, the instantaneous pressure peak is only half that required to burst the most fragile human eardrum ever observed (which was burst by a brief overpressure of 275 mbar, whereas 50 % of ruptures are observed at 1 bar).

Optimum dispersion of the suppressant is thus achieved without any risk of injury to personnel.

Belgian thermomechanical sensor

The initial impulse triggering the system is generated by a device which can react to two different effects of the explosion: the blast pressure in the roadway and the heat of the flame.

The nature of the phenomenon is of course such that the first of these effects always precedes the second; in incidents where the blast is still in an early stage of development, however, it may be useful to be able to rely on a flame-operated means of triggering the barrier in case the pressure does not reach the threshold for mechanical operation of the sensor.

Description of the sensor

The external appearance of the device is as shown in Figure 6. It is enclosed in a parallelepipedal steel case weighing almost 100 kg and having the following dimensions:

- height 66.5 cm
- width 30.5 cm
- length 46.5 cm.

Rings are fitted to the upper surface of the case so that it can be suspended, normally at the roof of the roadway. When so installed, the sensor need not necessarely hang vertically: it may be held to one side by a chain so that it does not obstruct the roadway cross-section.

When the sensor is in its operating position, the two opposite faces measuring 66.5 x 30.5 cm^2, which are provided with air inlets taking up 50 cm of their height, both lie in planes at right angles to the axis of the roadway.

The case thus allows a blast wave or flame to pass through in either direction while fully protecting the contents against all external mechanical damage (falling stones or other types of impact).

Most of the weight of the device is accounted for by the case, the removable equipment which it contains being comparatively light and easy to handle although it includes all the sensor mechanisms as shown in Fig. 7.

A description of the sensor mechanisms will be more readily comprehensible if combined with a discussion of the mode of operation.

Mechanical operation of the sensor

The blast of an explosion creates a dynamic pressure wave in the roadway, which causes a vane inside the case to swivel around, so that a blade severs a nylon cord which is held taut inside the casing parallel to the main axis.

This releases a hammer acted on by two tension springs. The hammer pivots about its axis and strikes a percussion primer in a cross piece mounted in the case; this is the point of connection between the sensor and the line of suppressor units.

Selective operation of the sensor is ensured by a special restraining system for the vane swivel, using a calibrated pin.

A second, more conventional locking system prevents any movement of the hammer during transport of the sensor apparatus, installation in the protective case and connection prior to commissioning.

Between 1977 and 1981 the following features of blast-operated triggering with the INIEX sensor were established by means of experiments, including tests in mine roadways.

- The sensor is mechanically operated by an explosion blast in a mine roadway at a dynamic pressure of 9 ± 3 mbar (static pressure at moment of operation 78 ± 18 mbar)
- The time elapsing between the arrival of the blast wave preceding a flame at a speed of 77.5 ± 16.5 m/s and the operation of the sensor is 106 ± 46 ms (under these conditions the operation of the sensor preceds the arrival of the flame front is 262 ± 71 ms).
- No spurious operation of the sensor is caused by a release of compressed air at 7 bars at the sensor inlet, by detonation of a charge of 350 g of dynamite suspended in a head end 35 m from the sensor or by firing of a round of 40 shots containing 22.5 kg of dynamite with the sensor 15 m from the blasting face.

Thermal operation of the sensor

In view of the extent to which mechanical operation is affected by the pressure level, triggering by thermal means alone may be regarded as a back-up mode to deal e.g. with combustion of a methane layer at roof level, where the flame speed is too low to cause an appreciable increase in pressure.

When a flame in a roof layer passes a sensor correctly suspended at the roadway roof, the nylon cord is severed by melting without any movement of the vane.

Severence of the cord, however it occurs, trigger the device. In the flame-operated mode this occurs a few tenths of a second after the flame has passed.

Monitoring of the continuity of the system

In order to derive all the safety advantages to be expected from a triggered barrier, especially when the system allows of a wide-action arrangement, one must be able to monitor its continuity, i.e. to check that it is in good working order when in industrial service.

In the INIEX system this monitoring is carried out on a constant basis providing a means of immediate detection and rapid location of any fault so that it can be eliminated, e.g. by replacing a suppressor unit which has been inadvertently damaged in the course of operations.

Principle of the continuity monitoring system

An electric circuit is incorporated in the detonation transmission line ensuring the operation of the barrier so that any break occuring in this line also interrupts the associated circuit.

The continuity of the electric circuit is in turn monitored by an electronic device which transmits a selected constant signal through it. This signal is sufficiently weak for the monitoring line to be intrinsically safe (first category) at all points on the output side of the wave generator.

Within the barrier itself, the electric monitoring circuit comprises an outgoing conductor, whose continuity depends on the transmission minidetonators being in contact and on the series of suppressor units being properly connected with the sensor(s), and a return conductor, which is in contact with the metalwork of all the quick-acting connectors used to link the various items.

The very action of installing the barrier by connecting up the various units and sensors thus has the double effect of creating a long detonation transmission line and at the same time an electrical circuit, the ends of the conductors being connected through a diode rectifier housed in a metal case with a quick-acting connector.

The diode case is generally placed at the inbye end of the barrier.

Wave generator

At the other end is the lead connecting the wave generator, which is housed in a set of flameproof enclosures, i.e., from bottom to top in figure 8:

- 1st enclosure : terminal box, high voltage side (220 or 500 V);
- 2nd enclosure : a 500 or 220 V/8 V transformer and main circuit breaker;
- 3rd enclosure : a battery with 4 sealed cells, each with a rated voltage of 12 V, and a printed circuit card with all the electronic components, viz.
  1. the stabilized power supply system connected in parallel to the battery, which is thus constantly recharged to ensure that the device will operate for over 24 hours if the mains network breaks down;
  2. the electric circuit whose function is to emit square waves down the monitoring line in order to indicate, by a system of red and green lamps, whether the circuit associated with the disperser line is complete or not;
- 4th enclosure : terminal box, low-voltage side (the electric circuit being intrinsically safe on the output side of this box).

Operation of the continuity monitoring system

The generator described above emits square waves down the disperser monitoring line. If everything is normal, these waves are rectified by the diode at the end of the monitoring circuit. If the monitoring line is broken, the signal received changes and the red bulb lights up in place of the green lamp.

An auditory signal can, if desired, be actuated at the same time as the red lamp, and all forms of signal transmission are of course possible.

A continuity fault may result from operation of the barrier or from a defect which can readily be located by dividing the line of suppressor units into sections which can be progressively eliminated by moving the diode case.

Pit trial

The robustness of the system and its suitability for use in industrial mining applications were assessed in 1977 in a colliery operating in the Campine Area.

A system which was complete except that it did not include any explosive element and which included apparatus for constant monitoring of the integrity and continuity of a line of 30 suppressor units was installed in the return gate of an advancing face.

The gateroad was driven by mechanized means and the explosion barrier was not moved. One year later, the equipment was still in very satisfactory condition, as can be seen from Figures 9 to 11.

With regard to the sensor, the removable apparatus including all the mechanisms was taken from its protective case on site; it was weighted with about 50 g of dust adhering to its various parts and on examination proved to be in working order.

The same applies to the continuity monitoring system, whose response time was checked with particular care.

The suppressor units, with one exception, seemed to be intact and perfectly watertight. The colliery had of course arranged for inspection of the water levels and the units had been topped up in the course of the year without difficulty.

Final considerations and future outlook

The Belgian triggered barrier system which has just been described seems quite capable of fulfilling the expectations arising from the lines of approach adopted at the outset of the research.

All its component parts are easy to handle and install, compact and sufficiently robust to satisfy the reasonable requirements of mining practice.

It can be adapted to different operating situations by arranging its suppressor units as concentrated or wide-action barriers.

A single explosion barrier can readily be filled with several thermomechanical sensors and if the suppressor units are arranged in the wide-action configuration the line is thus equipped with a 'multipoint' sensing system, as mentioned at the beginning of this paper.

Operation is then guaranteed irrespective of the direction in which the explosion is propagated. Provision of a number of sensors also has the advantage that it virtually eliminates the risk of failure of the sensing arrangements.

Moreover, there is no reason why a line of Belgian-type suppressor units should not be combined with a thermal or optical flame sensor developed by establishment other than INIEX. Such sensors are designed, on receipt of the predetermined signal, to emit an electrical impulse which can be used to trigger a set of electric detonators. If they were used in conjunction with the INIEX suppressor units it would be possible to ensure intrinsic safety of the firing circuit, which need include only one electric detonator.

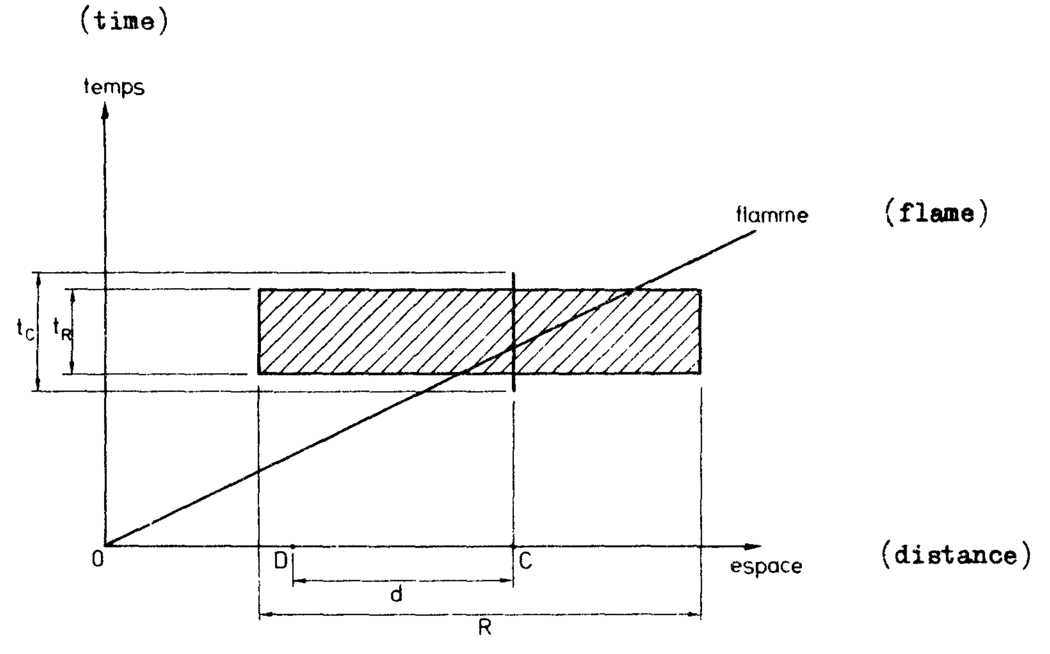


Figure 1

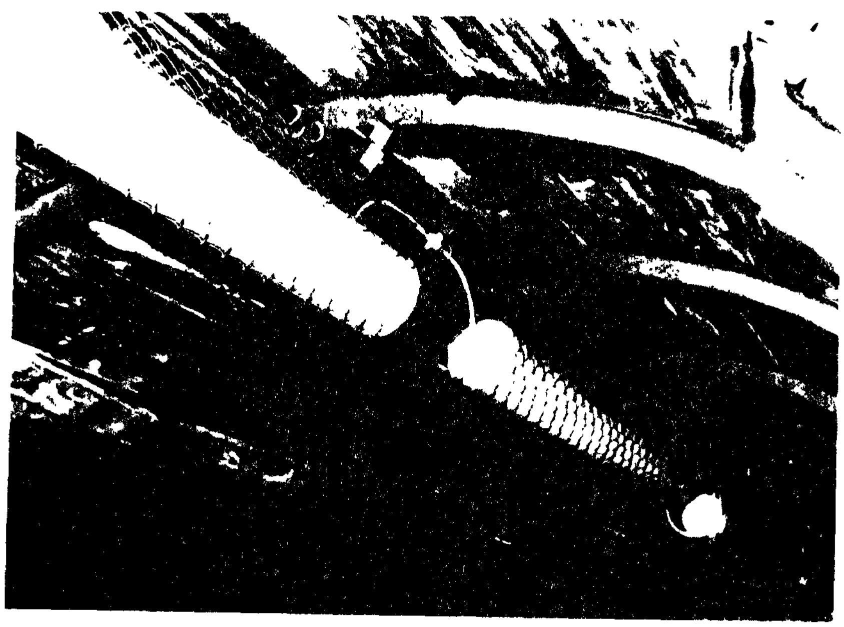


Figure 2

0 m

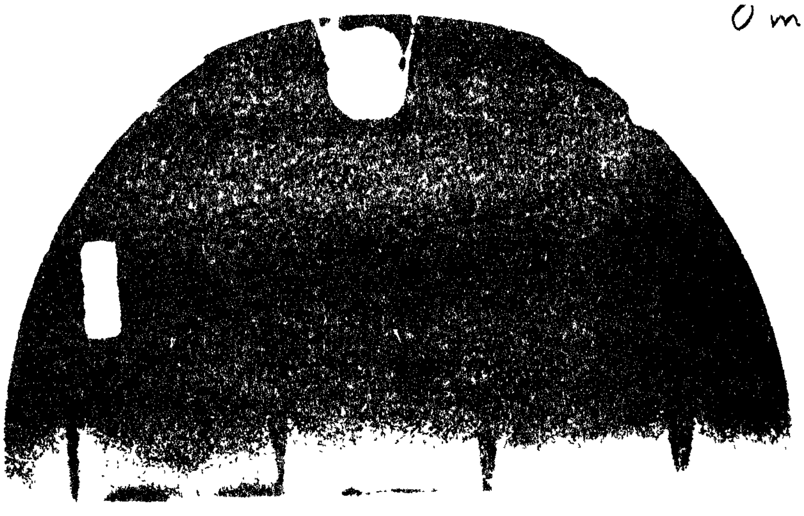


Figure 3

65

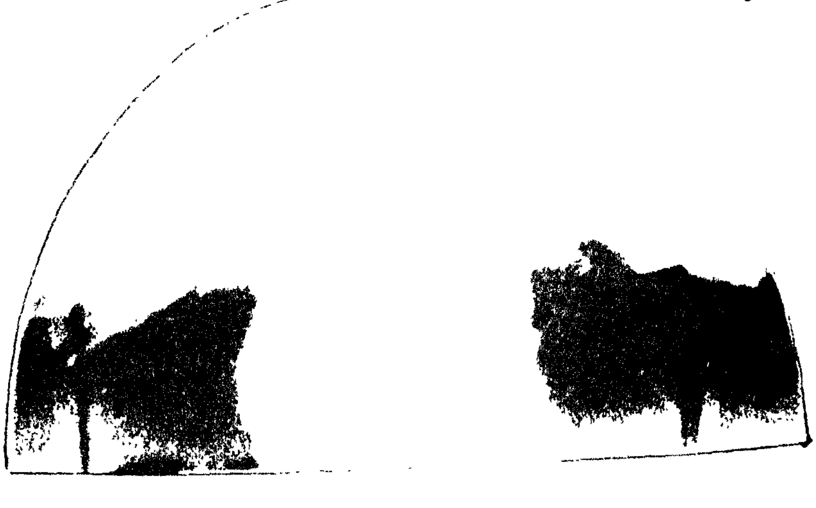


Figure 4

Figure 5

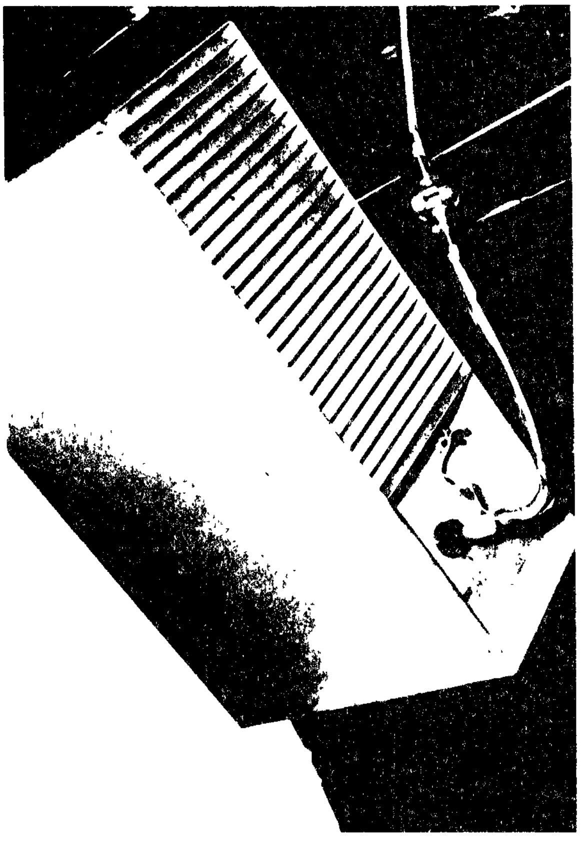


Figure 6

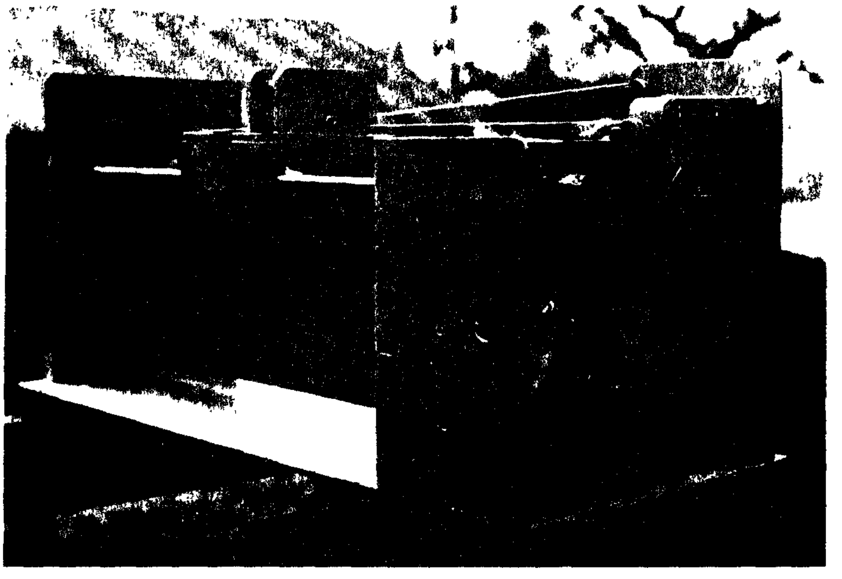


Figure 7

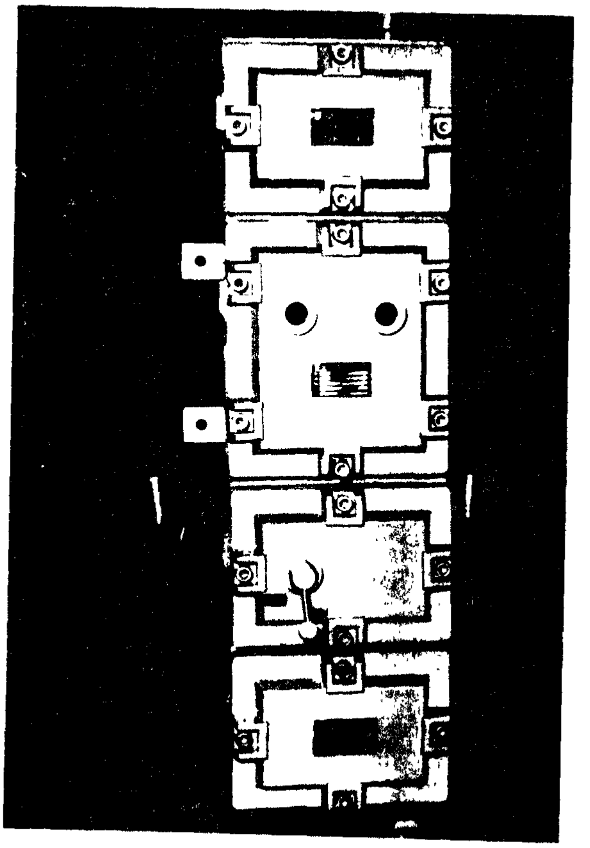


Figure 8

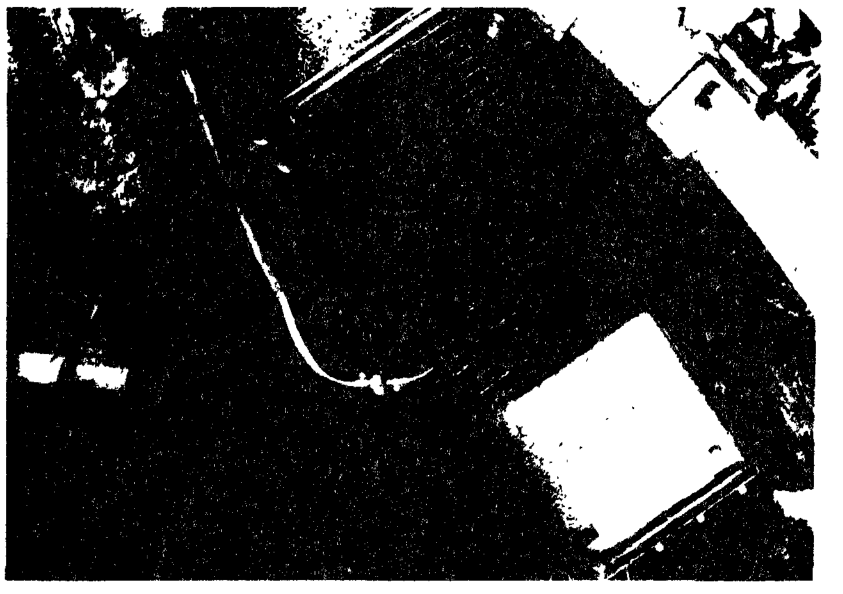


Figure 9

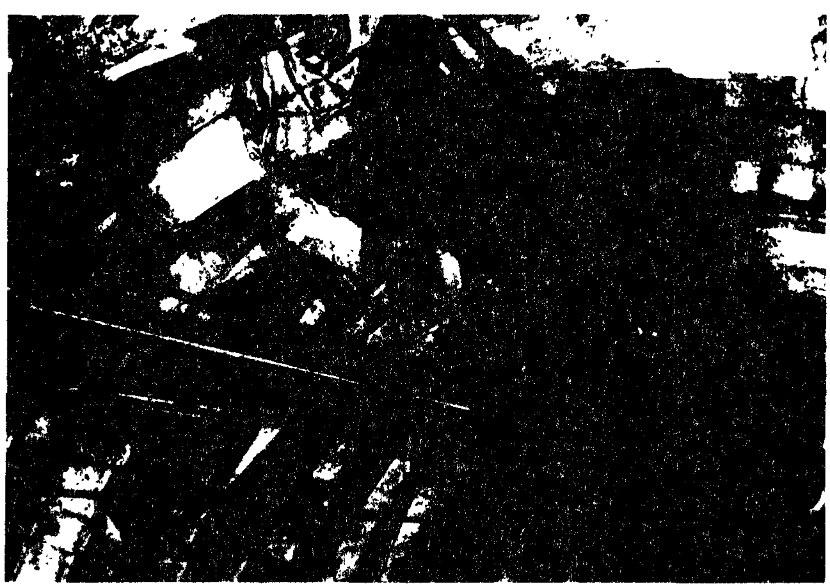


Figure 10

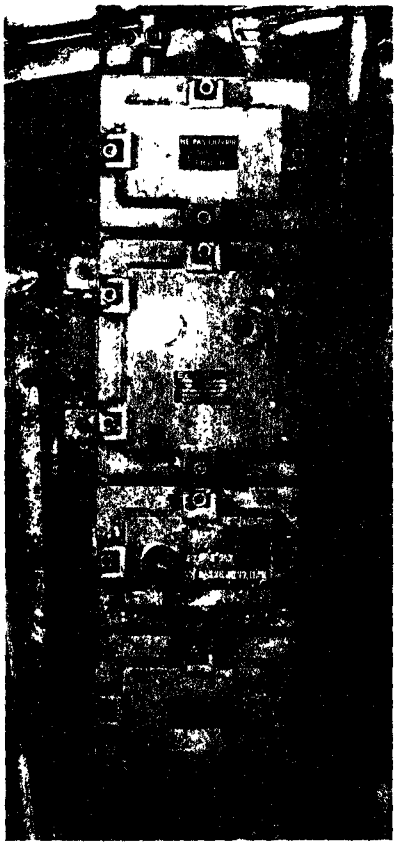


Figure 11

THE BELGIAN TRIGGERED BARRIER SYSTEM PERFORMANCE IN A CUL-DE-SAC TEST GALLERY

P. Goffart

In 1980, the system was subjected to performance tests in an experimental gallery. The following is a description of these tests.

Generally speaking, the suppressor units form a line several tens of metres in length in the gallery and thus offer the advantages of a wide-action arrangement. The water-to-air ratio, which is expressed in litres per cubic metre of gallery to be protected, varies according to the distance between successive suppressor units (each suppressor unit disperses 50 l of water in the form of droplets when actuated).

Again as a general rules the line of suppressor units is provided with two thermomechanical sensors providing the advantages of 'multipoint' detection.

Only for specific experimental purposes is a test sometimes carried out with a short suppression line and/or a single sensor.

The basic aim of the experiments is to see whether the triggered system proves more effective in arresting mine explosions than a conventional (non-triggered) explosion barrier, especially in the vicinity of the source of ignition and in cases where there is only a gradual increase in flame speed as the explosion progresses.

Conventional water-trough barriers are known to be effective against violent dust explosions even if the flame speeds and pressures are high (speeds of several hundreds of metres per second and pressures of 2 to 5 bars), provided the water-to-air ratio is right. Such troughs, however, are ineffective in the initiation zone of a slow-pressure-rise explosion.

The full-scale test gallery

The experiments were carried out in 1980 at the Montlaville quarry used by the CERCHAR laboratories at Verneuil-en-Halatte.

The test gallery is in the form of a blind heading penetrating to a depth of 145 m at the foot of a rock wall (Fig. 1). Its cross section is trapezoidal and averages 10 m^2.

The gallery is driven in limestone rock with bolted roof and gunited walls, its average gradient being 1.5 % dipping towards the mouth.

It is equipped for the production of full-scale dust explosions of low or medium strength. The progress of the explosion is observed by recording the flame front arrival and the change in scalar pressure in various sections of the gallery as a function of time. The recording instruments comprise photoelectric cells and piezoelectric transducers mounted in one of the gallery walls (the photocells being located at the 5th, 15th, 25th, 35th, 60th, 75th, 90th, 105th, 125th and 140th metres and the piezoelectric transducers at the 5th, 60th, 90th and 140th metres from the closed end of the gallery).

Production of the dust explosions

Use was made of a standard coal dust and three types of ignition source to vary the explosion characteristics.

The dust deposit consisted of Montrambert coal, without admixture of inert dust (average v.m. content 24 % daf and inert content 9 %; ground to ensure an underflow of 75 % by weight on a screen of 75 micron mesh).

For each experiment, the gallery was washed and dried. Most of the coal dust, which was not mixed with inert dust, was then laid on the gallery floor and the rest on raised transverse supporting surfaces which could be readily tipped to throw the dust into suspension in the air. The type and number of these supporting surfaces depended on the strength of the source of ignition: if the blast initiated in the cul-de-sac was fairly strong from the outset, the dust explosion was propagated even if much less dust was placed on the raised surfaces than on the floor.

A total of 300 kg of coal dust was laid at a density of 3 kg per metre of gallery so that the concentration in the air would be at least 300 g/m^3 if all the dust were uniformly dispersed in the course of the explosion.

The following three sources og ignition were used.

a) Source 8

A pile of eight kilogrammes of pure coal dust was raised into suspension by a charge of 10 kg of permitted explosive and the resulting dust cloud was ignited one second later by a suspended charge of 350 g of dynamite.

This initiating explosion dispersed 4 x 8 kg of dust laid on paper strips stretched across the gallery at shoulder level between the fifth and tenth metres. Thus strengthened, the blast attacked the rest of the dust deposit laid on the gallery floor and a violent dust explosion was propagated along the gallery.

b) Explosive firedamp accumulation ignited with black powder

60 m^3 of firedamp/air mixture containing about 9 % methane were prepared in the first five metres at the closed end of the gallery behind a paper screen dividing off the methane chamber and the explosion was initiated by an electric powder fuse containing 10 g of black powder which was suspended at shoulder height in the gas.

The dust deposit started at the fifth metre, part of the dust being laid on the floor and part on 10 tipping shelves, each carrying 8 kg of dust and placed at a height of over 2 m on a wooden cross bar wedged between the walls.

The force of ignition depended on the position of the igniter in the gas chamber. It was placed either close to the rock face forming the end of the gallery or close to the paper screen.

c) Firedamp roof layer

15 m^3 of methane were released at roof level at the 21st metre and spread as a layer as far as the 35th metre because of the general slope of the gallery and the longitudinal profile of the roof. The gas was ignited by a thread of nitrocotton which passed trough the roof layer and was in turn ignited by a fusehead.

The dust deposit was laid between the 30th and 120th metres, partly on ten transverse tipping shelves of 8 kg capacity (one shelf every 10 m) and partly on the floor.

These were the initiating conditions under which the dust explosion developed most slowly.

Note

- With sources a) and b) the time datum is normally taken as the moment when the initiating current is applied to the electric detonator igniting the dynamite charge or to the electric powder fuse.
- With source c), ignition of the gas by the nitrocotton takes place more slowly and the times should be measured from the moment when flame is detected by the photocell at the fifth metre.

'Control' dust explosions

The CERCHAR technicians provided us with the records of dust explosions developing freely in the Montlaville gallery, one (experiment No 1174) ignited by source 8, and the other (experiment No 1042) by a roof layer.

Control experiment No 1174

The results are shown in the form of graphs in the attached Figure 2 and are also given in Table 2, which will be discussed in due course.

The maximum overpressures were in the region of 0.3 bars. The flame speed was 30 m/s initially and increased all the way along the gallery to reach about 200 m/s at the mouth.

The blast wave preceding the flame front progressed evenly at the speed of sound in the atmospheric air (the phenomenon could be readily observed in this case because of the use of high explosive as a source of ignition).

From the instrument readings it is possible to assess the rate of pressure rise, which is indicated on the graph above the 5, 60, 90 and 140 m marks along the horizontal axis. The rate of rise was 0.5 bar/s in the vicinity of the source of ignition and increased considerably once the explosion had travelled over 100 m.

Control experiment No 1042

The flame speeds resulting from initiation of the dust explosion by a firedamp at the roof were only about 10 m/s initially and 75 m/s at the mouth of the gallery.

The overpressures did not exceed 0.1 bar.

The results of experiment No 1042 are included in Table 6 and illustrated by the graphs making up Fig. 6, which will be discussed in due course.

Experiment No 1203

This experiment was carried out at our request with a roof-level firedamp layer but without any dust deposit (in addition, a thermomechanical sensor was located in the gas layer at the 15th metre).

The optical effects of the flame were recorded as far as the 60th metre and lasted for about 300 ms; they were not apparent beyond this point.

The flame speed increased from 12 to 28 m/s.

The overpressure did not exceed 0.06 bar.

The results of experiment No 1203 are included in Table 5 and illustrated by the graphs making up Fig. 6, which will be discussed in due course.

Design of the triggered barrier experiments

As the test gallery had an average cross-section of 10 m^2 and was straight, without changes of direction or junctions, while the explosions were weak or of medium strength and were to be suppressed close to their initiation zone, it was in principle sufficient to have a single suppressor unit at any one point in the gallery, i.e. an in-line configuration.

The line of suppressor units extended from the 15th to the 100th metre and was suspended from a bar placed more or less above the centre of the gallery 2.6 m from the floor in such a way that the minimum clearance between the suppressor units and the floor was 2 m (Fig. 3).

As a general rule, in each of the tests thus carried out with a single line of suppressor units, two thermomechanical sensors were placed at different points along the line.

Each sensor was suspended in one of the corners between the wall and roof of the gallery and was held to one side by chains so that the gallery cross-section was obstructed as little as possible (Fig. 3).

Results of experiments with explosion barriers

Dust explosions initiated by explosives (source 8)

Arrangements for the experiments 1175 - 1176 - 1177 - 1179 were as shown in Table 1.

The results shown in Table 2 were obtained by the use of photo-electric cells (optical flame sensing) and piezoelectric transducers (scalar pressures).

Details of the 'control' explosion 1174 are shown in Table 2 for purposes of comparison.

In none of the experiments with triggered barriers was flame detected at 60 m. The overpressures were of the same order of mignitude as in explosion 1174.

The experiments confirmed the intervals between the arrival of the blast wave and mechanical operation of the sensor and between mechanical sensor operation and flame front arrival.

Graphs of the results of experiment 1177 are attached as Figure 4 for comparison with those for explosion 1174 (Fig. 2).

It was observed (by means of a contact installed for the purpose at the end of the connecting line linking the barrier and D_1) that the barrier was triggered level with D_1, 0.23 s after initiation of the explosion, i.e. 50 ms after the blast wave had passed D_1 and hence, as can be seen from the graph, at a time when the wave had not yet reached D_2. The barrier must thus have been mechanically triggered by sensor D_1.

Bearing in mind that the dispersion process once established lasts 350 ms, the gallery was filled with water droplets throughout the 78 m barrier zone 0.23 + 0.15 = 0.38 s after the time datum. The flame was quenched in the cloud of water droplets dispersed in this section of gallery at a rate of 1.25 litres/m^3 and was not detected at the 35th metre or beyond.

<u>Dust explosions initiated by an accumulation of firedamp</u>

The following apparatus was used for experiments 1201 and 1205:

- a single sensor placed at the 35th metre;

- 10 (5) suppressor units disposed in a line 40 m (20 m) long between the 15th and the 55th (35th) metres ensuring a water-to-air dispersion ratio of 1.25 l/m^3.

The results are shown in Table 3.

The flame was suppressed as soon as it started to propagate.

Graphs of the results of experiment 1201 are attached as Fig. 5. The barrier was triggered 1.16 s after initiation of the explosion, 160 ms after the flame front had arrived at the 15th metre, i.e. at the beginning of the line of suppressor units.

Dispersion of the suppressant filled the gallery with water droplets throughout the 40 m barrier zone 1.16 + 0.15 = 1.31 s after the time datum. The flame was quenched in this section and was not detected at the 35th metre or beyond.

The pressure rises were gradual and it is scarcely possible to determine the rates of rise from the readings. The single sensor used, which was placed at the 35th metre, clearly operated mechanically.

Dust explosions initiated by a roof layer of firedamp

- Experiments with a single sensor

In experiments 1206 and 1207, which may be compared with the control experiment 1203, there was no dust deposit and the firedamp roof layer extending to the 35th metre was thus the sole cause of the explosion.

The single sensor used was placed in the roof layer at the 15th metre. The line of suppressor units also began at this point and extended to the 70th metre.

To permit comparison with 1203, the test parameters for experiments 1206 and 1207 are shown in Table 4 and the results in Table 5. It is clear that a water-to-air ratio of at least 1 litre/m^3 was required to ensure that the firedamp reaction was no longer detectable by optical means at the 60th metre. Expansion of the combustion gases was halted although there could a considerable delay (of about 700 ms) in the thermal operation of the sensor.

- Experiments with two sensors

The following apparatus was used for experiments 1180 - 1208:

- two sensors, D_1 and D_2, placed at the 15th and 50th metre respectively;
- 21 (22) suppressor units arranged in a line 82 m long between the 15th and 97th metres, providing a water-to-air dispersion ratio of 1.25 (1.35) litres/m^3.

These experiments may be compared with the control experiment 1042 and experiment 1089.
The results of the latter experiment were made available to us by the CERCHAR staff. A conventional explosion barrier was used comprising four pairs of water troughs of 80 litres capacity placed at the 35th, 55th, 75th and 95th metres (water-to-air ratio in the zone between the 35th and 95th metres : 1 litre/m^3).

The results of experiments 1042, 1189, 1180 and 1208 are shown in Table 6.

A set of graphs is appended as Figure 6.

It shows the results of the experiments which gave rise to the lowest overpressures, viz. the control experiments 1042 and 1203, experiment 1189 with water troughs and experiment 1208 with the triggered barrier.

It also indicates the arrangements for the experiments and the duration of light radiation at the last photocell at which the arrival of the flame was recorded in each explosion.

In experiment 1208, the barrier was triggered 500 ms after the arrival of the flame at the 15th metre. D_1, which was located at this point in the firedamp layer, operated thermally while D_2 at the 50th metre operated mechanically. It is not possible to determine whether the barrier was triggered by sensor D_1 or D_2.

At all events, the explosion initiated by the firedamp deflagration was 'nipped in the bud'. The equipment installed in the gallery showed no signs of exposure to flame beyond the 22nd metre. This is clear from the photographs taken before and after test explosion 1208 (Figures 7 to 30).

Note

Especially after experiments 1175, 1177, 1180 and 1208, each of which involved a fairly large number of suppressor units releasing about 2 tonnes of water in all, the dust deposit in the test gallery, not only in the barrier protection zone but also for a considerable distance outbye (in the direction of explosion propagation) was so effectively 'inerted' that no dust explosion could occur within the time required to take action after a mine explosion and to instal a new explosion barrier.

Wide-action triggered barriers thus avoid 'repeat' explosions - an advantage which certainly is not offered by the concentrated barrier.

Conclusions and future outlook

It is clear that in the full-scale experiments carried out in the CERCHAR test gallery in 1980 the Belgian triggered barrier system lived up to expectations.

This cul-de-sac gallery of tropezoidal cross section simulates mining conditions which are of great importance in industrial practice (coal and stone drivages).

It would be desirable to test the system under other operational conditions, e.g. those encountered at the face/gate junction, as there is at present no explosion barrier which can be used in practice in such situations.

In order to carry out such tests, we would have to find a suitable location and to be able to count on the same spirit of cooperation as was shown by our CERCHAR colleagues.

TABLE 1

CERCHAR EXPLOSION NO	LINE OF SUPPRESSION UNITS: NUMBER	BEGINNING (m)	END (m)	LENGTH (m)	WATER DISPERSED (litres)	WATER DISPERSED (l/m^3)	POSITION OF SENSORS (metre): D_1	D_2
1175	21	15	97	82	1 050	1.25	16	50
1176	9	15	97	82	450	0.50	16	50
1177	20	15	93	78	1 000	1.25	35	70
1179	9	15	97	82	450	0.50	35	70

TABLE 2

CERCHAR EXPLOSION NO	MAXIMUM OVERPRESSURE (bar): at 5 m	at 60 m	at 90 m	MEAN FLAME SPEED (m/s): 5-15 m	15-35 m	35-60 m	60-75 m	75-90 m	INTERVALS (ms) ::: t_p	t_F	t'_F
1174	0.28	0.32	0.24	30	75	95	95	115	-	-	-
1175	0.30	0.28	0.16	32	40	-	-	-	+ 80	- 320	- 320
1176	0.30	0.28	0.16	30	55	-	-	-	+ 100	- 270	- 270
1177	0.24	0.22	0.16	29	-	-	-	-	+ 50	-	- 270
1179	0.32	0.32	0.26	40	40	-	-	-	+ 140	- 610	- 140

:: t_p is the interval between the arrival of the blast wave at sensor D_1 and triggering (observed level with D_1)

t_F is the interval between the arrival of the flame front at sensor D_1 and triggering (observed level with D_1)

t'_F is the interval between arrival of the flame front at the 15th metre and triggering (observed level with D_1)

TABLE 3

CERCHAR EXPLOSION NO	MAXIMUM OVERPRESSURE (bar)			MEAN FLAME SPEED (m/s)					INTERVAL (ms)*
	at 5 m	at 60 m	at 90 m	5-15 m	15-35 m	35-60 m	60-75 m	75-90 m	t'_F
1201	0.20	0.20	0.20	11	-	-	-	-	+ 160
1205	0.28	0.27	0.26	21	-	-	-	-	+ 90

* t'_F interval between the arrival of the flame front at the 15th metre and triggering (observed level with sensor D placed at the 35th metre); this is the only time interval which can be determined from the observations.

TABLE 6

CERCHAR EXPLOSION NO	MAXIMUM OVERPRESSURE (bar)				MEAN FLAME SPEED (m/s)								INTERVAL (ms)
	at 5 m	at 60 m	at 90 m	at 140 m	5-15 m	15-35 m	35-60 m	60-75 m	75-90 m	90-105 m	105-125 m	125-140 m	
1042	not recorded		0.09	0.01	7	12	30	45	55	19	20	75	-
1189	0.21	0.21	0.19	0.04	17.5	17.5	50	55.5	79	79	-	-	-
1180	0.36	0.32	0.21	-	25	50	-	-	-	-	-	-	400
1208	0.12	0.12	0.08	-	21	27.5	-	-	-	-	-	-	500

* t_F in experiments with the triggered barrier, is the interval between the arrival of the flame front at sensor D_1, i.e. at the 15th metre, and triggered (observed level with D_1)

TABLE 4

CERCHAR EXPLOSION NO	LINE OF SUPPRESSION UNITS						POSITION OF SENSOR D (m)
	NUMBER	BEGINNING (m)	END (m)	LENGTH (m)	WATER DISPERSED (litres)	(l/m^3)	
1203	0	-	-	-	-	-	15
1206	6	15	70	55	300	0.55	15
1207	12	15	70	55	600	1.10	15

TABLE 5

CERCHAR EXPLOSION NO	MAX. OVERPRESSURE (bar)			MEAN FLAME SPEED (m/s)				INTERVAL t_F:: (ms)
	at 5 m	at 60 m	at 90 m	5-15 m	15-35 m	35-60 m	60-75 m	
1203	0.06	0.05	0.04	12	15	28	-	320
1206	0.10	0.08	0.06	16	13	34	-	720
1207	0.10	0.06	0.05	11	11	-	-	750

:: t_F is the interval between the arrival of the flame front at sensor D and the operation of this sensor

List of illustrations

1. Mouth of the CERCHAR test gallery

2. Graphs for control experiment 1174

3. Cross section of gallery with explosion barrier

4. Graphs for experiment 1177

5. " " " 1201

6. " " experiments 1042-1189-1203- 1208

Photographs of experiment 1208

Before the explosion

7. View at the 97th metre of the 22nd suppressor unit and the connection with the electric continuity monitoring cable

8. View of suppressor units 20, 21 and 22 looking towards the mouth of the gallery

9. Research assistant in the gallery at the 90th metre beside units 20 and 21

10. View inbye from the 50th metre showing suppressor units 9 to 5

11. View of the inbye end of suppressor unit 6 at the 35th metre

12. View towards the mouth of the gallery, showing suppression units 6, 7, 8, 9 and 10 in series

13. View of the outlet pipe at the 21st metre for the gas used to form the roof layer

14. View of sensor D_1 installed at the 15th metre

15. Side view of sensor D_1 showing its connection to the line of suppressor units and the diode rectifier at the end of the line

16. View of the nitrocotton igniter for the roof layer at the closed end of the gallery

17. View from the 10th metre towards the mouth of the gallery

18. Laying of the coal dust at the 110th metre

19. End of the dust deposit at the 120th metre

After the explosion

20. View inbye from the 120th metre

21. " " " " 100th metre

22. View of the line of suppressor units starting at the 22nd unit

23. View of the line of suppressor units looking inbye from the 18th unit (80-82 m)

24. " " " " " " " " " " " 12th unit (57-59 m)

25. " " " " " " " " " " " 7th unit at 38 m

Note the step in the roof at the 6th unit.

26. Side view of the 2nd unit (20-22 m) with traces of exposure to heat at 20 m and not at 22 m

27. View of sensor D_1 and the 1st unit (16-18 m)

28. Side view of sensor D_1, also showing the T connection, the diode rectifier and the imbye end of the 1st suppressor unit

29. View from the 2nd suppressor unit, looking along the line of units towards the mouth of the gallery.

30. Electrical apparatus for constant continuity monitoring of the triggered barrier system

Figure 1 : Mouth of the CERCHAR test gallery

Fig. 2

EXPERIMENT 1174
(control)

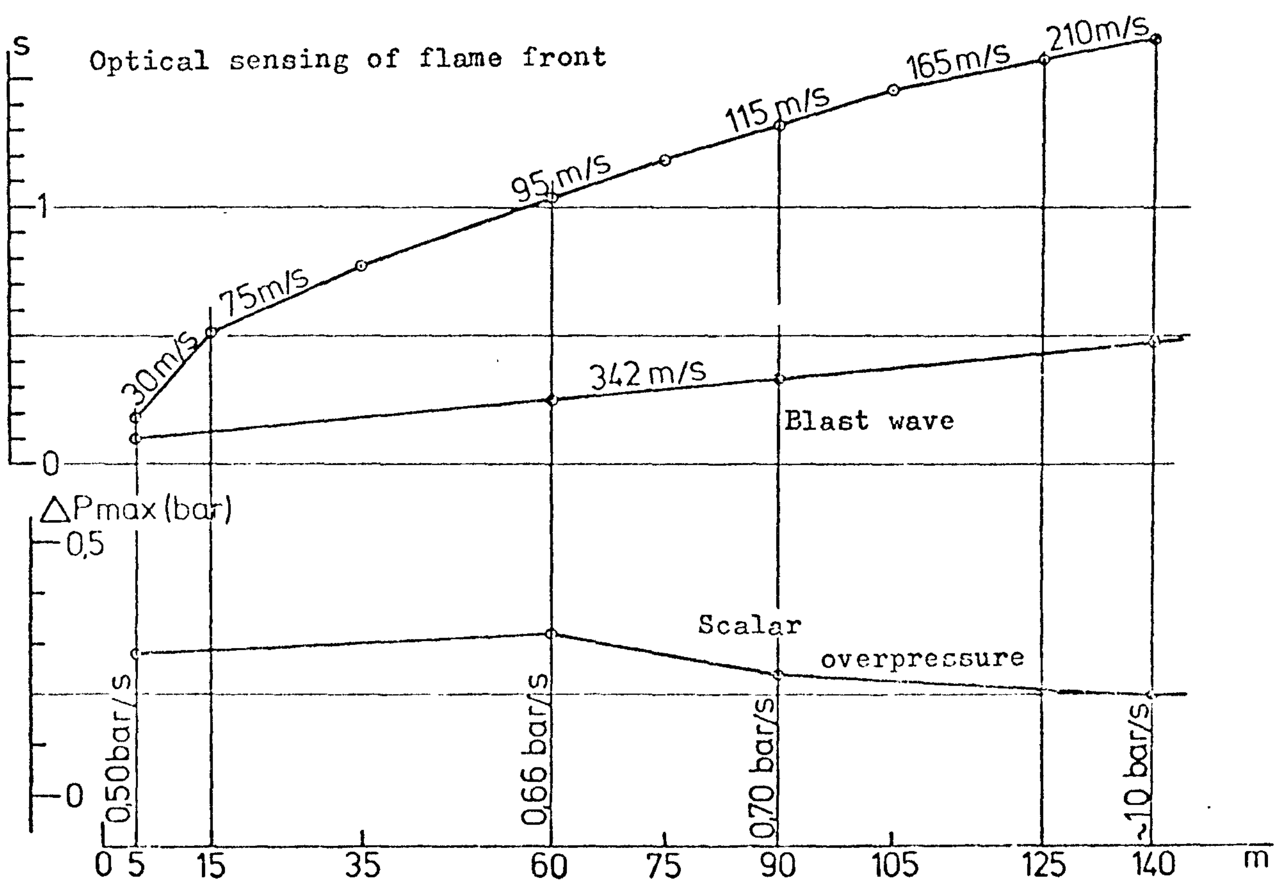


Fig. 3

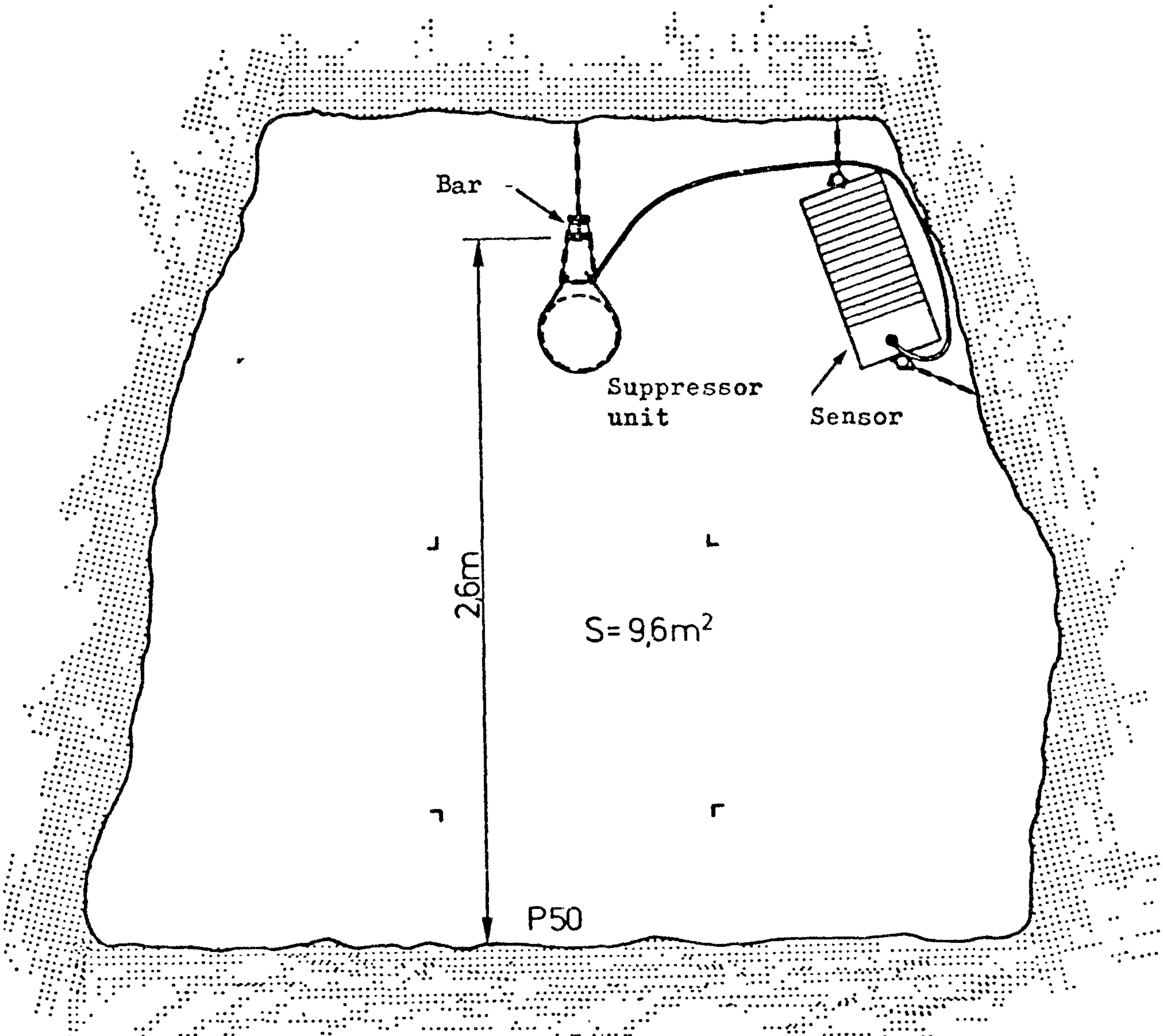


Fig. 4

EXPERIMENT 1177

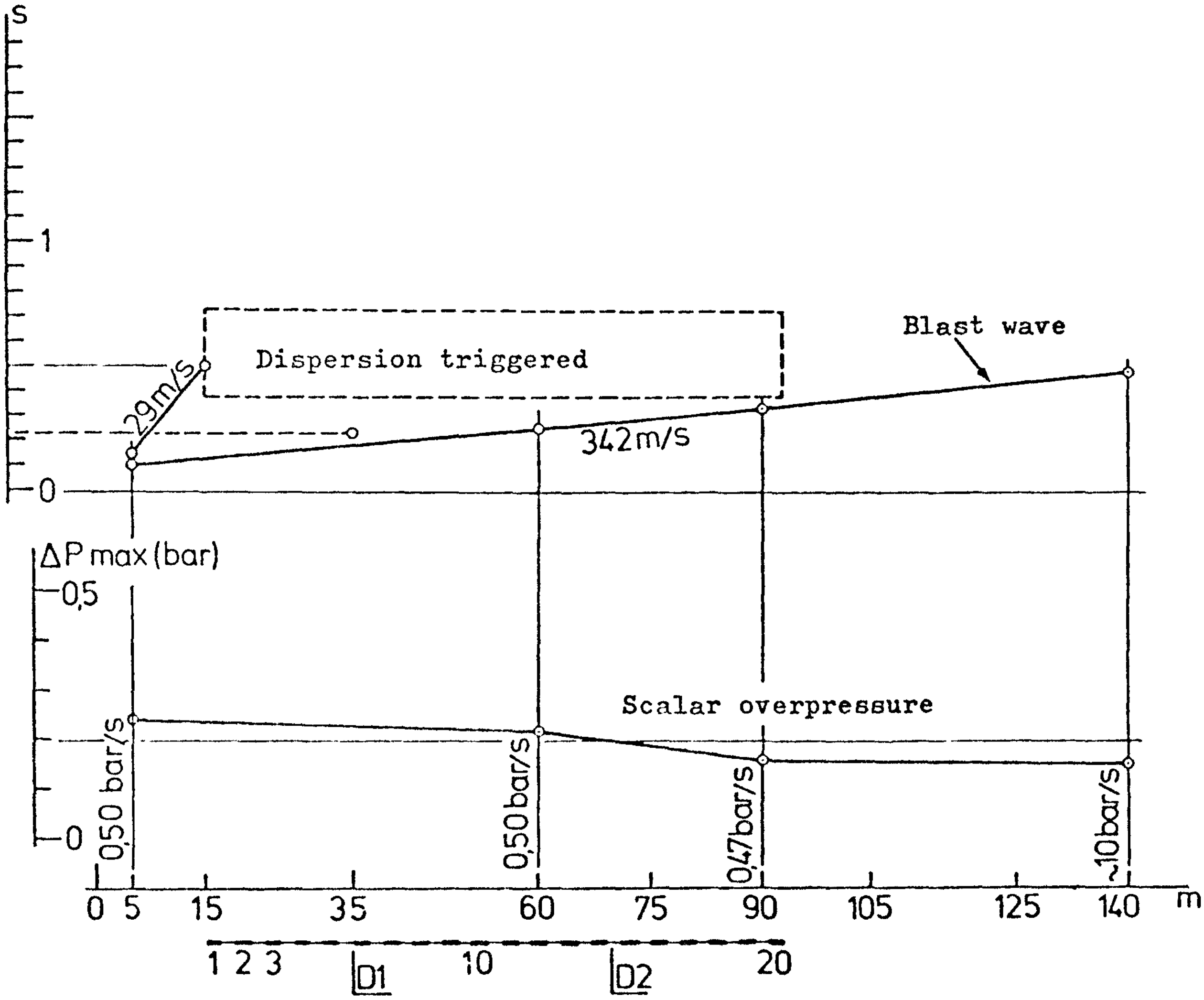


Fig.5

EXPERIMENT 1201

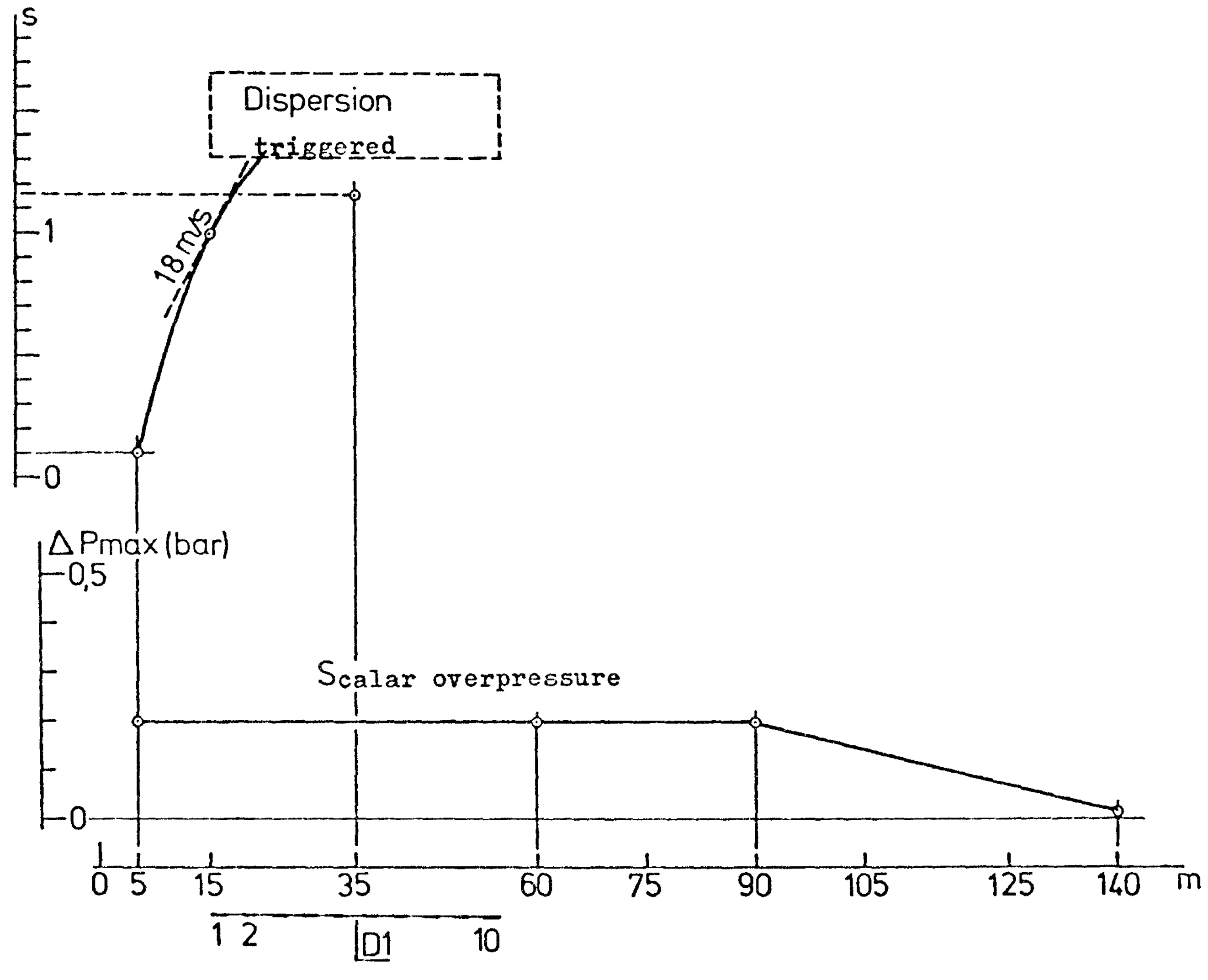


Fig. 6

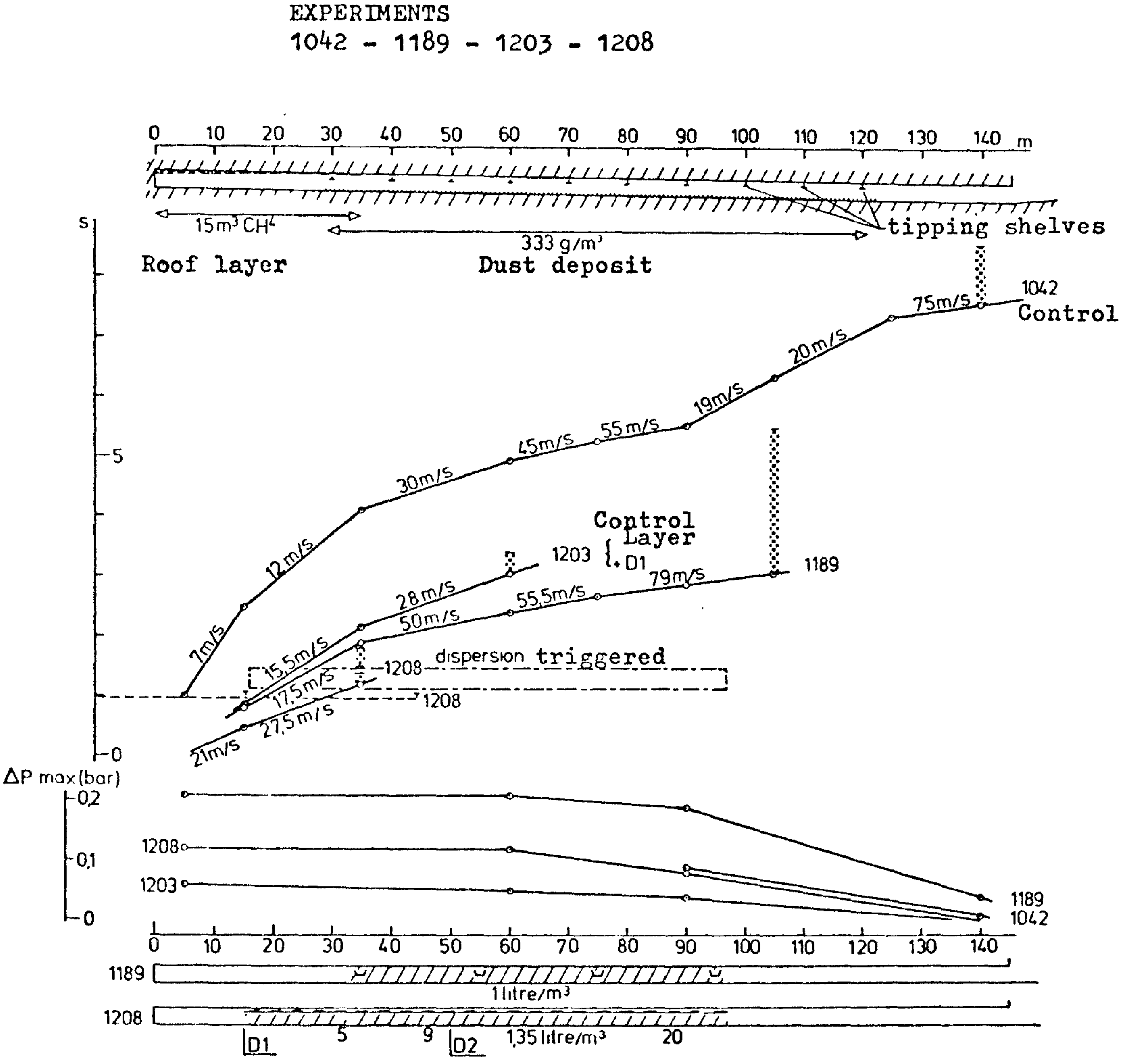

EXPERIMENTS
1042 - 1189 - 1203 - 1208
15m³ CH4
333 g/m³
tipping shelves
Roof layer
Dust deposit
1042
Control
75m/s
20m/s
19m/s
55m/s
45m/s
30m/s
12m/s
7m/s
Control
Layer
1203
D1
1189
79m/s
28m/s
55,5m/s
50m/s
15,5m/s
17,5m/s
27,5m/s
21m/s
1208
dispersion triggered
ΔP max (bar)
0,2
0,1
0
1208
1203
1189
1042
1 litre/m³
1,35 litre/m³
D1
D2
m
s
5

Figure 7 : View at the 97th metre of the 22nd suppressor unit and the connection with the electric continuity monitoring cable

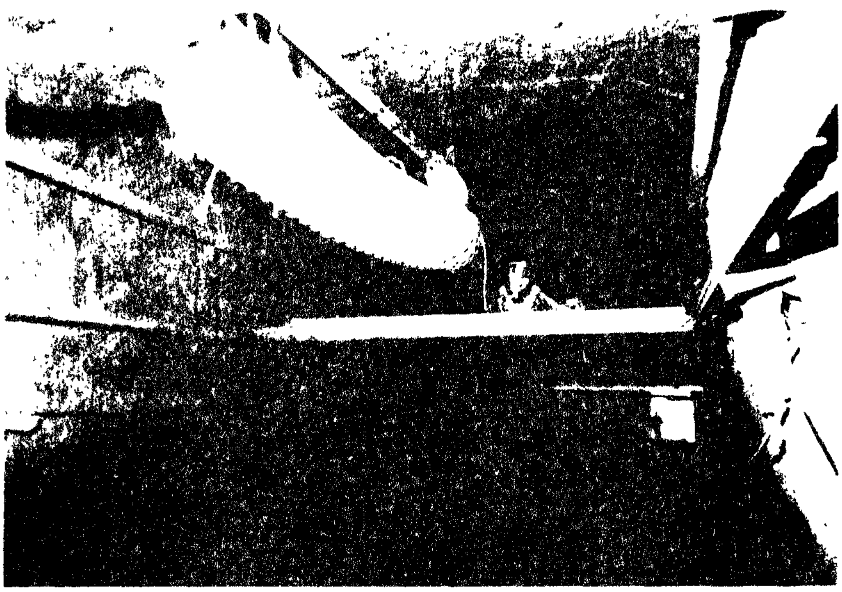


Figure 8 : View of suppressor units 20, 21 and 22 looking towards the mouth of the gallery

Figure 9 : Research assistant in the gallery at the 90th metre beside units 20 and 21

Figure 10 : View inbye from the 50th metre showing suppressor units 9 to 5

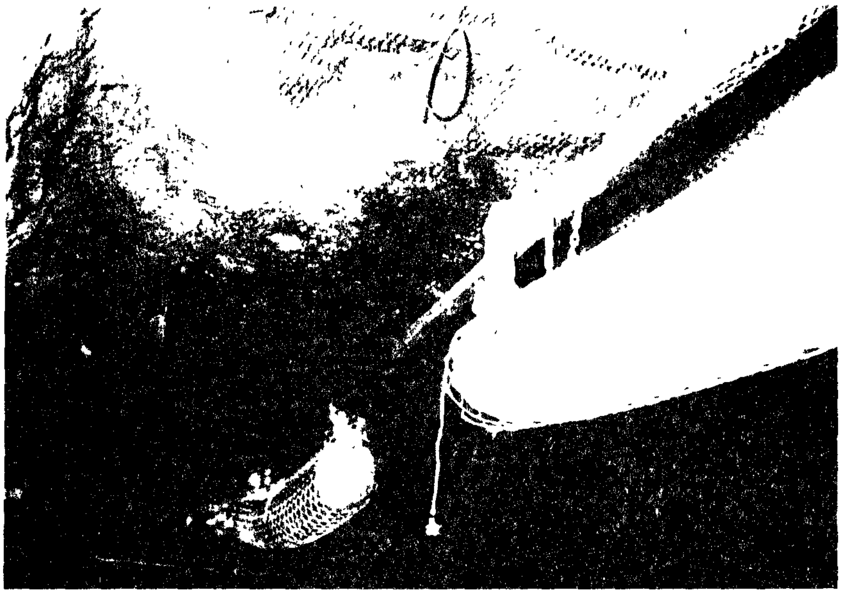


Figure 11 : View of the inbye end of suppressor unit 6 at the 35th metre

Figure 12 : View towards the mouth of the gallery, showing suppression units 6, 7, 8, 9 and 10 in series

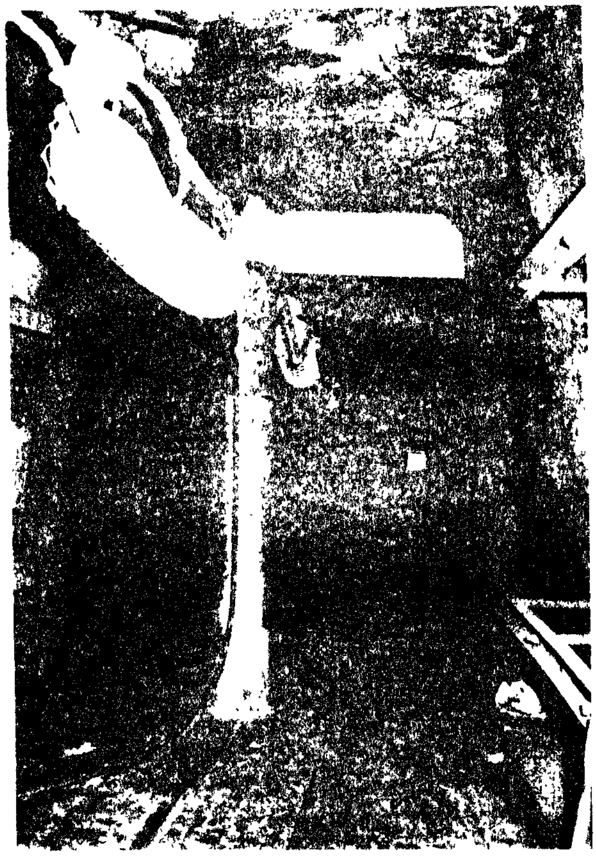


Figure 13 : View of the outlet pipe at the 21st metre for the gas used to form the roof layer

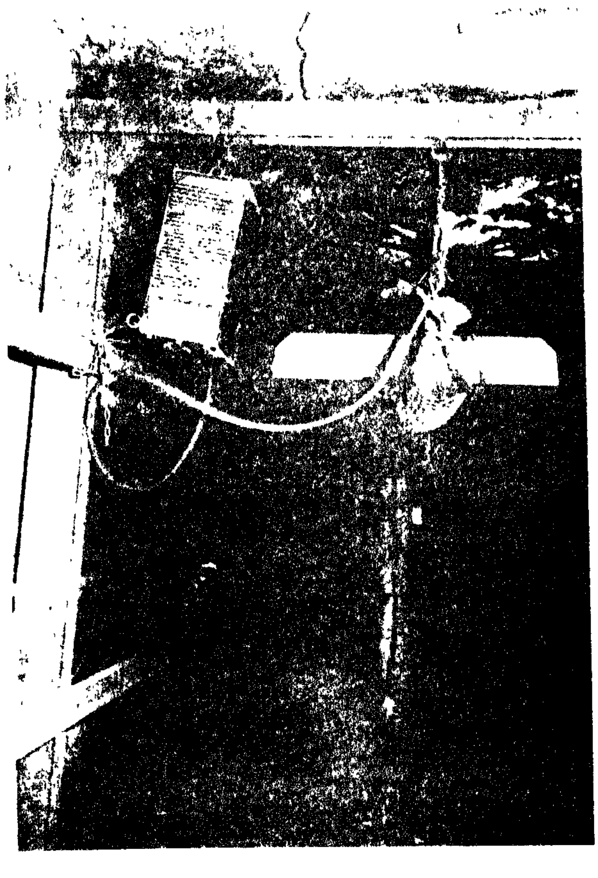


Figure 14 : View of sensor D_1 installed at the 15th metre

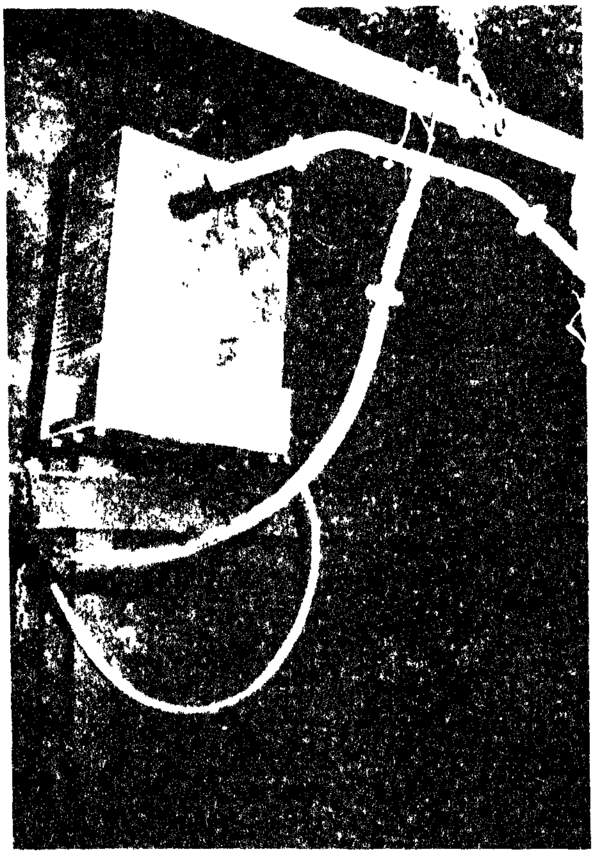


Figure 15 : Side view of sensor D_1 showing its connection to the line of suppressor units and the diode rectifier at the end of the line

Figure 16 : View of the nitrocotton igniter for the roof layer at the closed end of the gallery

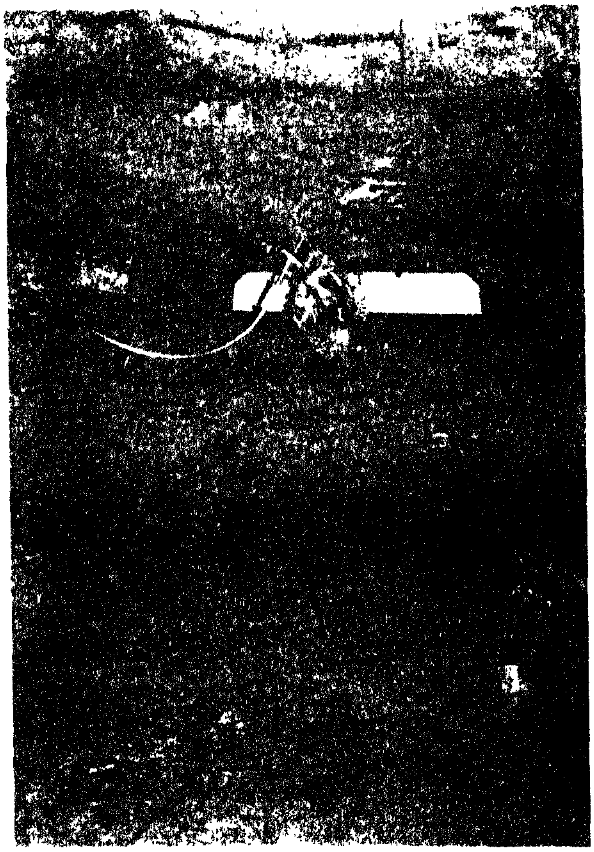


Figure 17 : View from the 10th metre towards the mouth of the gallery

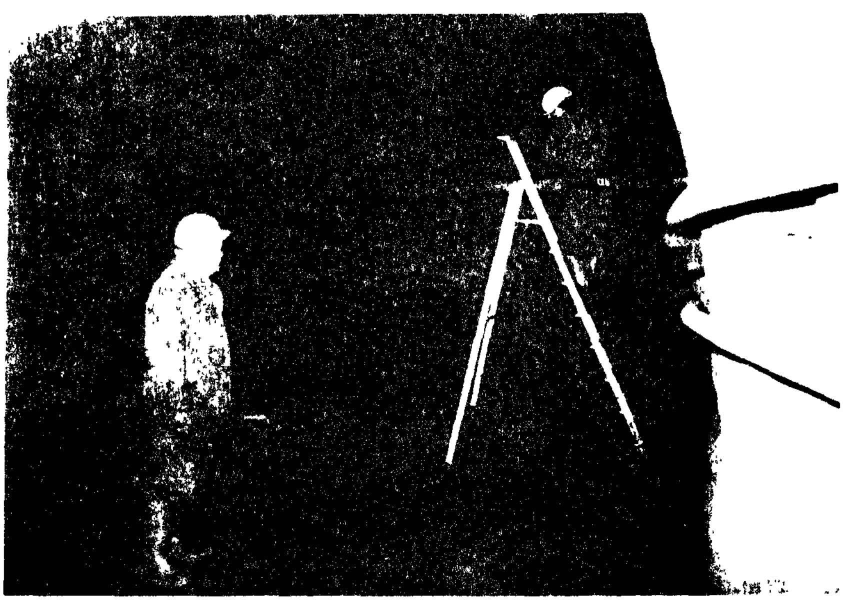


Figure 18 : Laying of the coal dust at the 110th metre

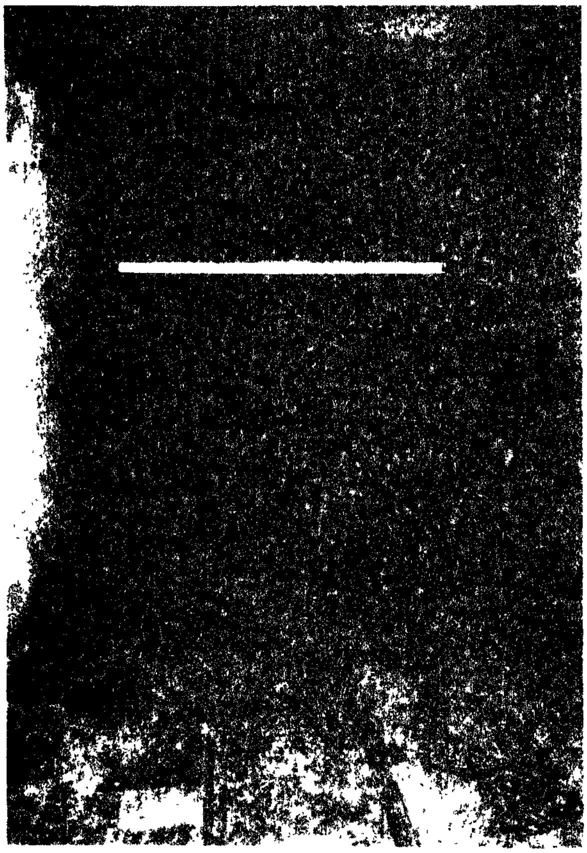


Figure 19 : End of the dust deposit at the 120th metre

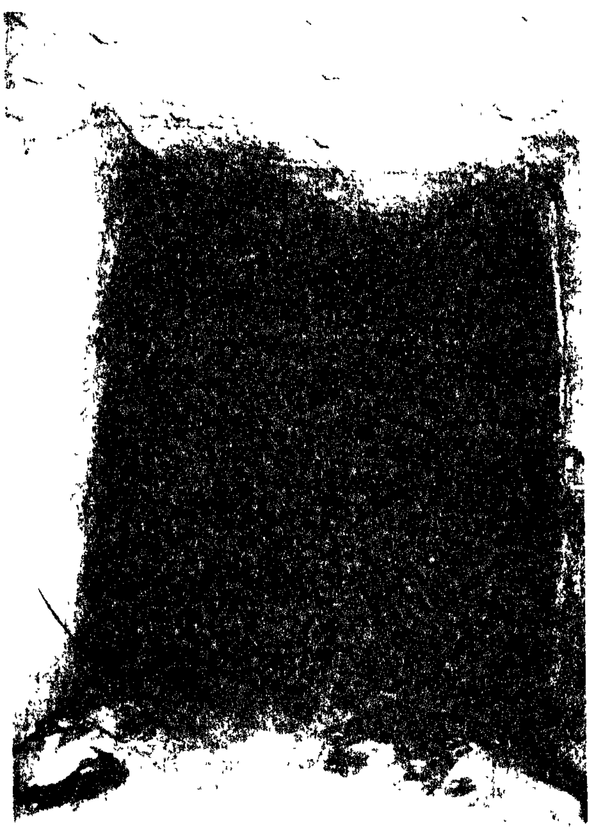


Figure 20 : View inbye from the 120th metre

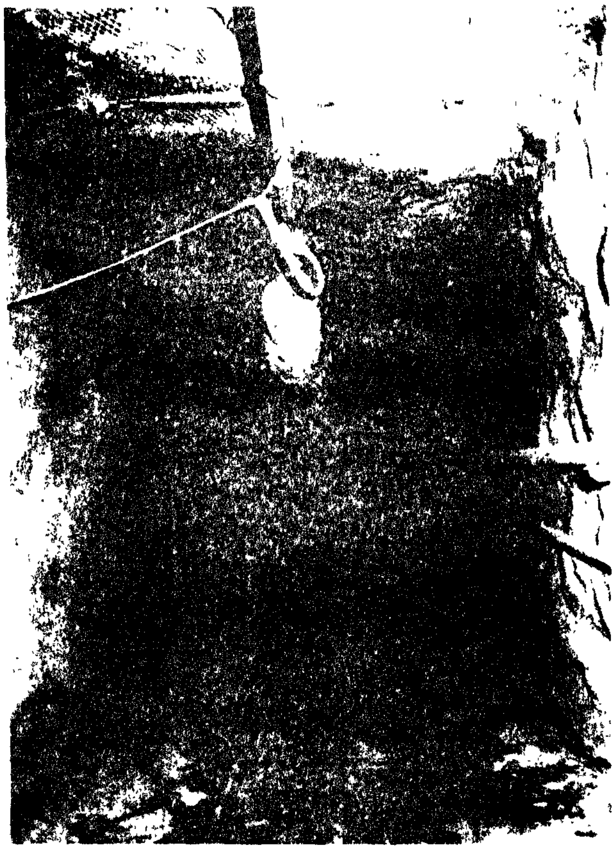


Figure 21 : View inbye from the 100th metre

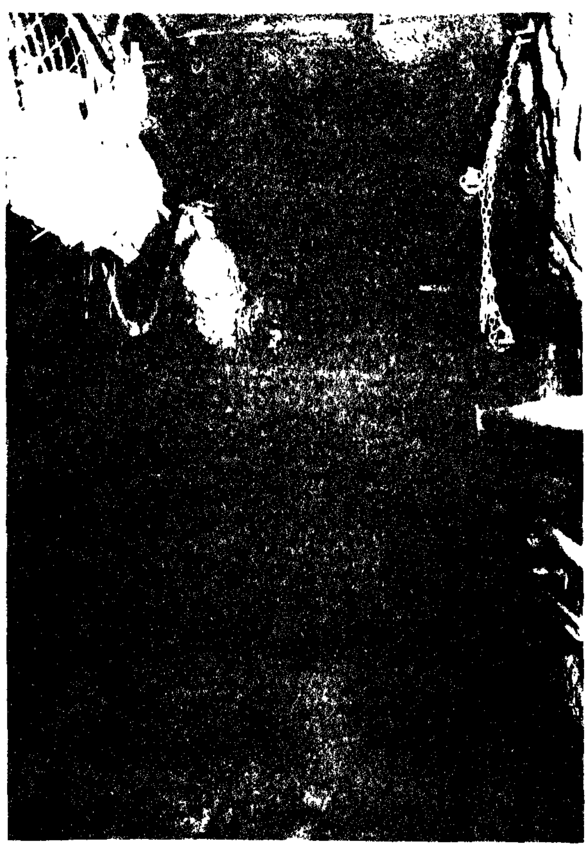


Figure 22 : View of the line of suppressor units starting at the 22nd unit

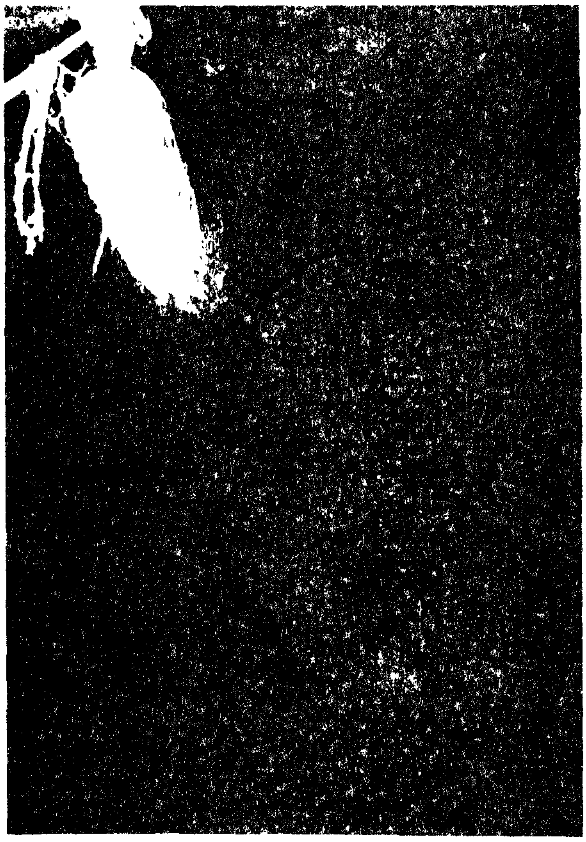


Figure 23 : View of the line of suppressor units looking inbye from the 18th unit (80-82 m)

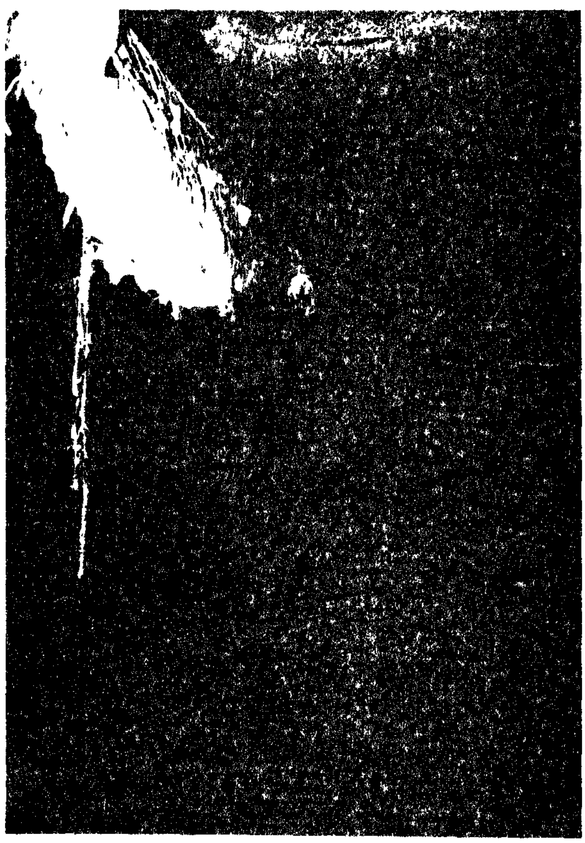


Figure 24 : View of the line of suppressor units looking inbye from the 12th unit (57-59 m)

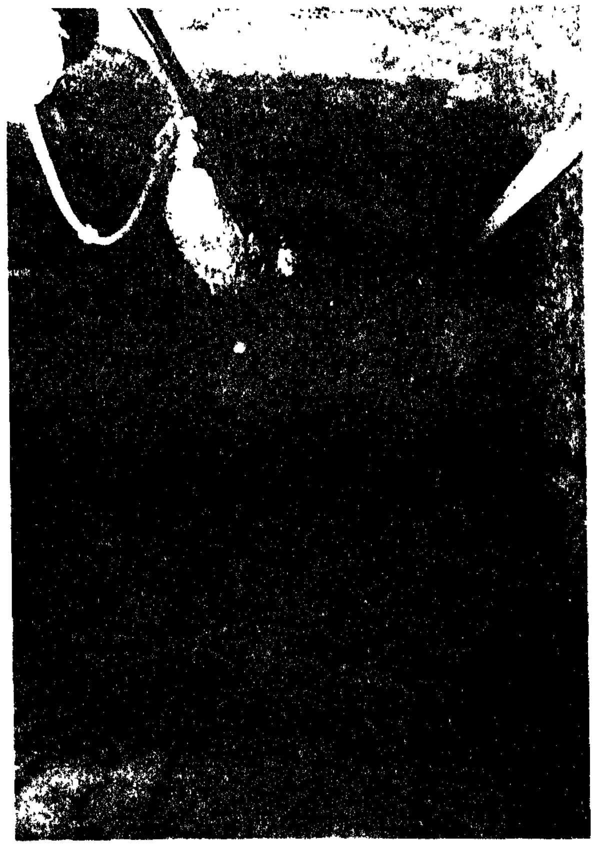


Figure 25 : View of the line of suppressor units looking inbye from the 7th unit at 38 m

Note the step in the roof at the 6th unit

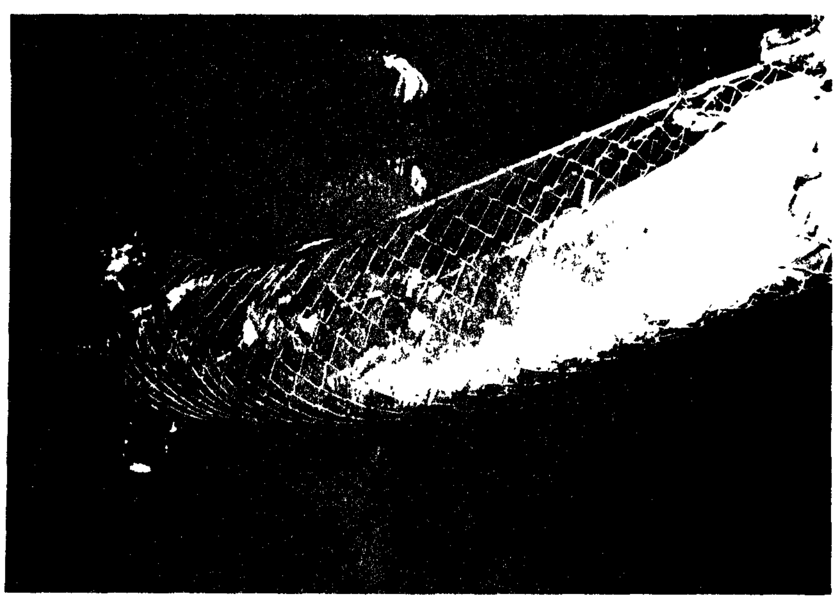


Figure 26 : Side view of the 2nd unit (20–22 m) with traces of exposure to heat at 20 m and not at 22 m

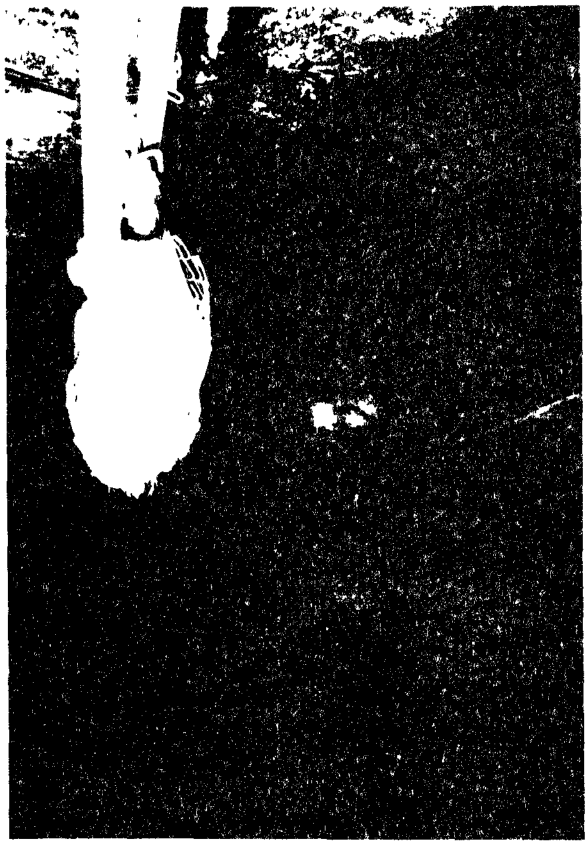


Figure 27 : View of sensor D_1 and the 1st unit (16-18 m)

Figure 28 : Side view of sensor D_1, also showing the T connection, the diode rectifier and the inbye end of the 1st suppressor unit

Figure 29 : View from the 2nd suppressor unit, looking along the line of units towards the mouth of the gallery

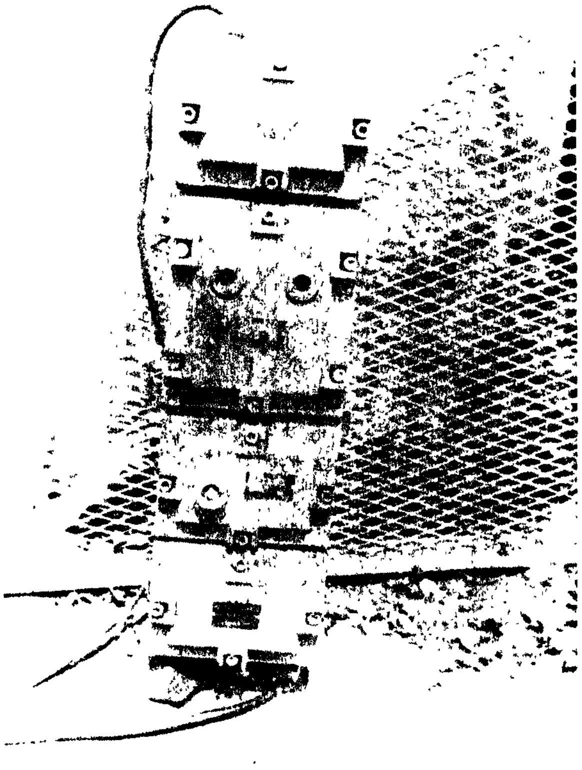


Figure 30 : Electrical apparatus for constant continuity monitoring of the triggered barrier system

Current research on triggered barriers by the Health and Safety Executive

by

D. Rae

1. The SMRE triggered barrier has been described briefly in Technical Information Leaflet 'Explosion 1' which is annexed to this note. The barrier has been approved for use in the UK, after having been tested in nearly full-scale conditions, and a number of systems are now in operation. The limitations imposed by the tests impose limitations on the installation of the barriers underground. Present research is directed towards making the present barrier more acceptable by reducing these limitations, and also towards finding ways of making such barriers more effective.

2. The Buxton test facility has, in the past, only been used for tests in explosions of coal-dust and air mixtures; it is being modified so that firedamp and hybrid explosions may also be made. The opportunity will be taken to examine how well the barrier behaves when there is some firedamp in the atmosphere in order to determine whether the siting of sensors and dispersers should be modified in potentially gassy situations.

3. The present siting of sensors and dispersers has been arrived at because no single sensor-to-disperser distance could be found that would be satisfactory both for the whole range of explosion violences to be expected underground, and for those that could be produced in the test facility. The double system was arranged by adding two single systems of sensor and disperser together. In a double system it is possible that the action of one disperser will be aided by that of the other. It is hoped that tests will show that a double system will allow a greater range of face movement before barrier movement is necessary, but it is not expected to show any large increase. The test zone in the Buxton gallery will be lengthened

by adding arches up to 140 m. This will lead to potentially stronger explosions should a barrier fail, so that the range of strengths of test explosions will have to be a little more limited.

4. Low, wide roadways are not simulated very well by the Buxton gallery; however, it would be of advantage, in view of the need for effective barrier protection in low, wide roadways, if tests could be carried out in a sufficiently long gallery of low, wide configuration.

5. The SMRE triggered barrier has been developed particularly for low, wide roadways, but this configuration, about 2 m high and 4.5 m wide, causes installation difficulties. In order to ensure that coal dust in any part of the roadway cross-section is acted upon by the water from the disperser, it is necessary that the point of introduction of the water into the roadway cross-section shall not be too far away. A limit of 2 m has been placed on this distance. It would be of practical benefit if this limit could be increased. The 2 m limit is based on findings in the Buxton gallery that short, asymmetrical stone-dust shelves or water containers are not very effective when more than about 2 m away from a strip of coal dust, and also because in tests in the low, wide roadway at Tremonia, no part of the roadway cross-section was more than about 2 m away from the disperser. Current understanding of how coal-dust explosions propagate and what effect the water has on this process are not sufficiently advanced to enable a theoretical approach to be made. However, if the movement of the water perpendicular to the axis of the roadway is shown to be sufficiently rapid, it may be possible to make a small increase in this limit. Although some velocity is given to the water on emission from the disperser, the initial speed is limited by the consideration that it must not cause injury during inadvertent operation. The penetration of droplets

into a stream flowing at right angles depends greatly on particle size, which for this barrier is unknown because the water is broken up after emission by the explosion. It is proposed to make a study of the movement of the water away from the disperser, during explosions.

6. Various proposals for part-width shelf and water container barriers have been put forward over the years; these generally combine the introduction of inert material from the barrier into that part of the cross-section of the roadway most likely to contain coal-rich dust together with a requirement for a high concentration of inert dust in the other parts. An examination will be made of how far this concept can be applied to the current barrier in use in low, wide roadways. Criteria will have to be arrived at for the proportion of the roadway cross-section considered to be covered by the SMRE triggered barrier, where the limits of 7 m^2 per 220 - kg disperser and 2 m maximum cross-sectional distance apply.

7. Intermediate and heavy stone dust shelf barriers are also installed in UK mines, and are also difficult to erect and maintain in low, wide roadways. These barriers are capable of suppressing stronger explosions than the triggered barrier described above, and a preliminary assessment is being made of the operating characteristics likely to be required by a similar triggered barrier system that would replace them.

8. Barriers should, ideally, be designed from an understanding of the mechanisms of flame propagation and suppression. The Buxton gallery is particularly well suited to the use of scientific apparatus, and optical and radiation studies of the composition and temperature of gases and the temperature of particles are being carried out. The apparatus is currently

under construction. The immediate aim of this work is an attempt to establish which part of a coal-dust explosion flame is most readily affected by the application of suppressant material. The longer term aim is a combustion and aerodynamic model of coal-dust explosion that will enable barriers to be developed for situations where the simple geometry of a gallery is not applicable.

D. RAE
16.3.81

Health and Safety Laboratories

Technical Information Leaflet

Explosions 1

Triggered barriers for the suppression of coal-dust explosions

When the Health and Safety Executive was formed at the beginning of 1975, the Safety in Mines Research Establishment, with laboratories at Buxton and Sheffield, and the Occupational Medicine and Hygiene Laboratories at Cricklewood were brought together The laboratories have been reorganised and their staff and the range of their activities increased; the laboratories are now known collectively as the Health and Safety Laboratories (HSL).

These leaflets give brief accounts of individual aspects of the work of HSL. A general account of the work is published each year in "Health and Safety Research 1977" etc (HMSO). These annual reports also give information about more detailed accounts of the work published elsewhere.

INTRODUCTION

Coal dust underground may be raised into the air by the blast from a firedamp explosion, and this airborne dust may be ignited by the burning firedamp. Combustion of this dust supplements the blast which may raise more coal dust as fuel for the flame, and a self-propagating coal dust explosion may develop. Such an explosion can be suppressed at an early stage by a suitably designed barrier.

TIPPING BARRIERS

Existing barriers in British mines are of the tipping type, and consist of a series of shelves loaded with stone dust. These barriers are operated by the blast of the explosion itself to create a cloud of stone dust in the path of the flame. They are sited at specified positions to limit the spread of explosions originating at or near faces. Barriers loaded with water instead of stone dust have also proved effective in gallery tests, and can be used underground.

PRINCIPLE OF THE TRIGGERED BARRIER

Another form of barrier, known as a triggered barrier, consists of two parts separated by a predetermined distance. One part is a sensor which detects the arrival of a flame, and is usually a device that is sensitive to heat. The other part is a disperser which receives a signal from the sensor and rapidly discharges a suppressant material (usually water) into the path of the flame. Fig 1 shows a discharge of water from a disperser. The energy used to discharge the water is stored in the disperser and does not have to come from the explosion itself.

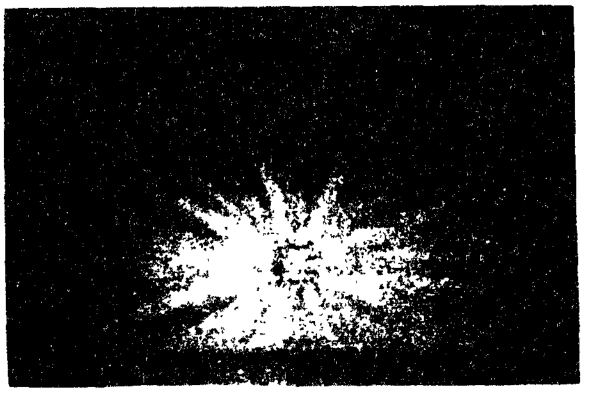


Fig 1 Discharge of water from disperser of triggered barrier

TRIGGERED BARRIER BASED ON MK II WATER DISPERSER

Since 1967 work has been concentrated on the development and testing of a triggered water barrier to perform the same function as the light stone-dust barrier. The triggered barrier comprises a thermocouple flame sensor and the Mk II water disperser (Fig 2) whose discharge is powered by compressed nitrogen. The pressurised nitrogen is retained by a fast-acting valve and the water is held in by a retaining plate. When a signal arrives from the flame sensor, the valve is opened and the nitrogen pressure is applied to the water, forcing off the retaining plate. The nitrogen drives a piston along the cylinder and 227 litres of water are discharged across the path of the explosion within about 180 milliseconds.

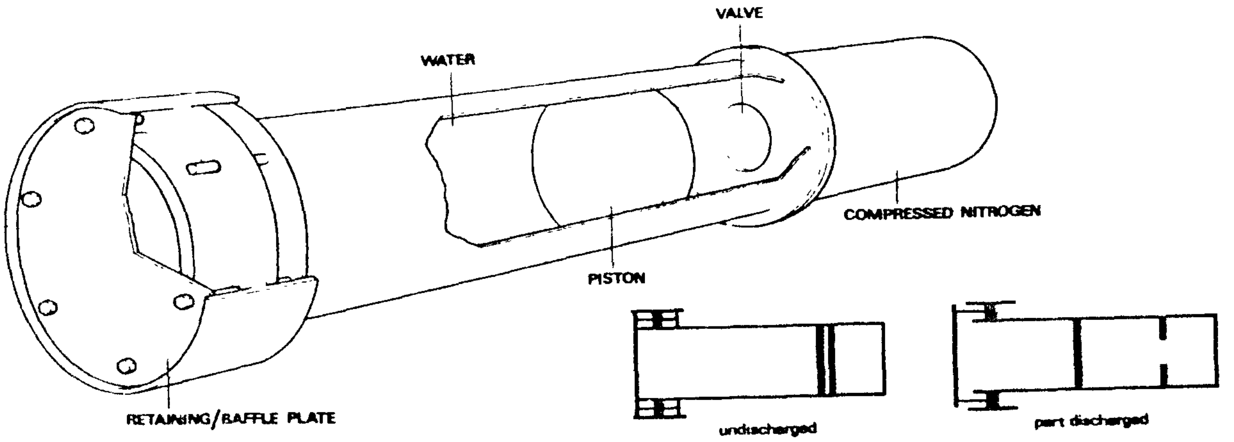


Fig 2 Diagrams of MK II disperser

TESTS ON TRIGGERED BARRIERS

Tests have been conducted on the Mk II disperser and the thermocouple sensor in the coal-dust explosion gallery at HSL's Buxton laboratory and also in the Tremonia Experimental Mine in West Germany. The tests at Tremonia were made in a full-size arched roadway and in a low wide roadway, against both coal-dust and methane explosions.

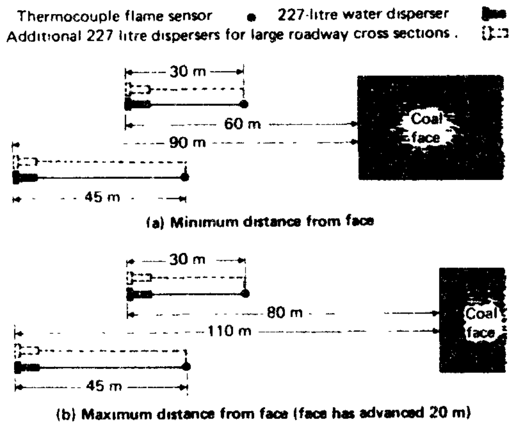


Fig 3 Recommended siting of triggered barrier

Different barrier arrangements were tested against explosions of different strengths and with different types of ignition source. As a result of the test programme, a system based on Mk II dispersers has now been recommended to the coal-mining industry as a suitable alternative to the light stone-dust tipping barrier. Fig 3 shows the recommended positions with respect to the coal face. For comparison, the first shelf of the light stone-dust barrier is sited 64 to 119 m (70 to 130 yds) from the line of the coal face.

ENVISAGED INSTALLATIONS

Light stone-dust barriers pose problems for the coal-mining industry, especially in those places where low headroom and rapid rates of advance make them difficult to install and maintain. In comparison the triggered barrier system is compact and can be moved quickly once it has been installed, and these should be major factors in its acceptance by the industry. Fig 4 shows a typical installation in a roadway with restricted height.

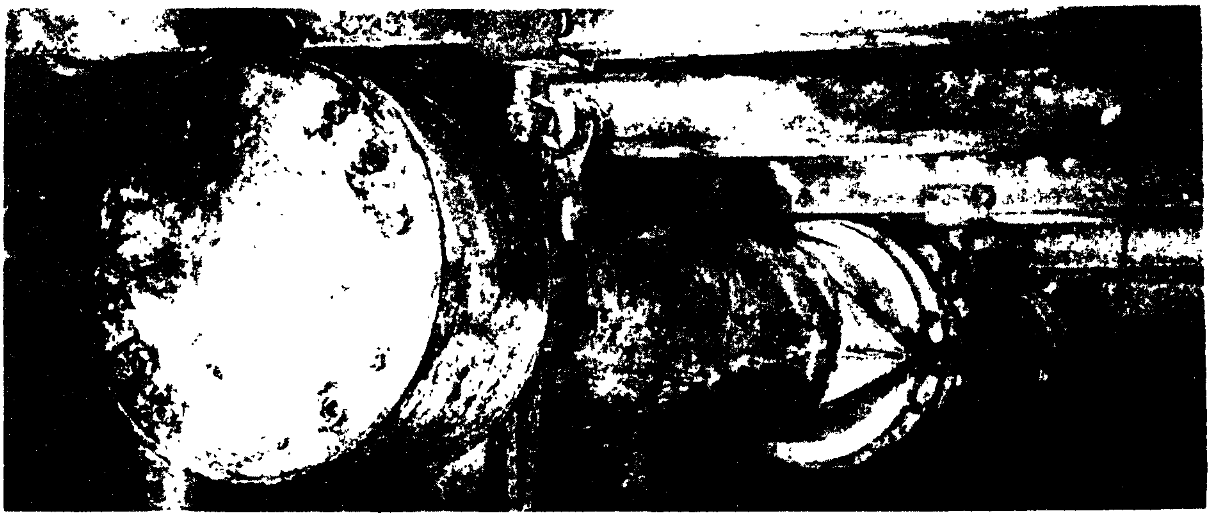


Fig 4 Mk II disperser in a low working

H. Jenderek

Essen, 17 August 1981

Explosion barriers and their current use in the Federal Republic of Germany

The development of triggered barriers has now reached the practical application stage and, under certain conditions, this equipment is more effective than conventional water trough barriers. Nevertheless, there are no signs so far of a general replacement of conventional barriers with triggered barriers.

As a result, we still have to deal with conventional water trough barriers. In particular, operational experience has revealed the need for changes in the regulations governing the design of these barriers, i.e. the 'design descriptions', but only, of course, where such alterations are warranted for the salce of explosion suppression.

Some time ago, the Working Party on Flammable Dusts presented the former Mines Safety and Health Commission with:

- an informative report on water trough barriers and
- a recommendation on the use of water trough barriers.

These documents were adopted by the MSHC on 22 January 1974 and 5 July 1977 respectively.

In them, the Working Party examined in particular the location of water trough barriers in mine workings and enumerated their advantages over stone dust barriers. However, details of the barriers themselves, including the regulations on installation of the water trough vanity, were restricted to the minimum required in the context.

In order to be able to report on experience in the operation of these barriers, I must first of all outline the specific requirements set out in the design descriptions.

The majority of water trough barriers used in the coal mines of the Federal Republic of Germany are:

- type 3 for concentrated explosion barriers and
- type 4 for wide-action explosion barriers.

Allow me first to give you a review of the main characteristics of concentrated water trough barriers, type 3.

These barriers consist of troughs containing about 90 l of water arranged in groups.

A group of troughs includes all troughs within a 3 m length of roadway.

Several groups of troughs make up one concentrated barrier. The barrier contains at least 200 l of water per square metre of roadway cross section and at least 5 litres per cubic metre of roadway space in the vicinity of the barrier.

The troughs are suspended from supporting frames and/or stand on supporting frames or trough supports.

Supporting frames, trough supports or other fixtures must be properly secured to the ground, roadway supports or installations.

Suspended and standing troughs may be used together within one and the same trough group.

The positioning of troughs in the roadway cross section is most important.

The trough groups must cover

at least 35 % of the maximum roadway width in cross sections of up to 10 m^2, at least 50 % of the maximum roadway width in cross sections of up to 15 m^2 and

at least 65 % of the maximum roadway width in cross sections of over 15 m^2.

The maximum individual and overall distances between the troughs within the trough groups are 1.2 m and 1.5 m respectively.

The troughs normally have to be positioned with their long side at right angles to the line of the roadway, but in certain circumstances one trough per trough group can be placed lengthwise.

The vertical distance between troughs within the roadway cross section may not be

under 0.8 m
or over 2.6 m downwards,
or over 2 m upwards.

If the distance upwards from one trough is over 2 m, a second trough must be installed above it.

Now we come to the wide-action water trough barriers, type 4.

Type 4, like type 3, consists of groups of troughs; the distance between the troughs however, may range up to 30 m.

The same rules apply for the formation of groups of troughs and their location within the roadway cross section as for type 3.

Each group of troughs must contain at least 1 liter of water per cubic metre of space in the roadway section up to the next group of troughs.

The nearest group of troughs to a roadway junction or crossing must be no more than 30 m away from it. In gateroads, the distance between the T-junction and the nearest groups of troughs must be as short as possible and not exceed 35 m. It may be increased to 60 m or 90 m if further troughs are placed in this area containing a specific amount of water, which varies according to the actual distance and roadway cross section.

Gentlemen,

These design descriptions, which were adopted at the end of 1970, were based on the results of studies carried out at Versuchsgrubengesellschaft mbH, Dortmund and Bergbau-Versuchsstrecke, Dortmund-Derne. Practical experience in the installation of former types of water trough barriers in coal mines was also taken into account.

We tried to limit requirements to what was regarded as necessary at that time for the suppression of explosions, and not to consider intricate means of adapting barriers to individual roadway cross sections, shapes of cross sections and fixed items of equipment. We therefore felt that we had eliminated, for the time being, the problems which had occurred in the past.

This expectation however, did not turn out to be true. In actual fact, the number of cases in which we have had to deviate from the design descriptions, i.e. the standard designs, has increased over the past few years. The approval of the Chief Mines Inspectorate has to be obtained in every case. Most of the cases have involved roadways with large cross sections containing the most varied types of fixtures and transport in the most diverse arrangements.

Experience so far shows that the following requirements of the design descriptions present the most frequent problems in practical operation:

- the requirement that 35 %, 50 %, or 65 % of the maximum roadway width must be covered by troughs;

- the maximum distance between the troughs: individually 1.2 m and 1.5 m overall;

- the minimum and maximum spacing of troughs downwards of 0.8 m and 2.6 m respectively;

- occasionally, the requirement that one trough only per group of troughs may be installed lengthwise.

These requirements presuppose that most of the roadway cross section is available to meet them. In actual fact, this is not always the case as shown by the following examples:

- a belt conveyor with 1200 mm and wider belts, irrespective of whether they are installed on the ground in the lower part of the roadway or suspended higher up. These problems become even worse when the remainder of the roadway cross section is taken up by track-mounted vehicles or overhead monorails;

- twin-strand belt conveyors also used for manriding;

- and, a recent development, diesel-powered trackless vehicles.

In these and similar cases, the design descriptions have to be adapted or special arrangements made for the installation of barriers in the roadway cross section.

The roadways concerned are both main roadways and mechanized roadway drivages or gateroads. The latter present special problems near T-junctions because of the energy trains located there.

Preparations for updating the design descriptions for water trough barriers have been made by the Committee of Experts on Operational Safety of the Steinkohlenbergbauverein and this task will be carried out by mine representatives and the expert bodies concerned; in particular, Versuchsgrube and Bergbau-Versuchsstrecke.

However, supplementing the design descriptions with operational requirements will not be enough.

Instead, all notable changes must be based on available explosion suppression data or be shown to be necessary by special studies. It is therefore not yet possible to foresee when this work will be completed and a new version of the design descriptions will become available.

COMPARATIVE STUDY OF FLAMMABLE DUST DURING DEPOSITION, DEPOSITED AND RAISED INTO THE AIR

R. LIBERDA

S U M M A R Y

This paper is a summary of two studies carried out in the Nord-Pas-de-Calais collieries :

- Comparison of dust during deposition and when deposited :

  This study was based on trials carried out using a CPM3 device, which is used in France to measure the harmful dust concentration. This instrument also allows larger dust particles to be collected. A comparison is drawn between the differences in dust concentration at two points in a roadway and in the quantities of dust deposited on plates between the two points.
  Chapters include : a study on correlation, results and a conclusion : the CPM3 dust samples provides no sure information on the quantities of flammable dust deposited.

- Comparison of settled dust and dust raised into the air :

  Here we have studies carried out on dust deposited in roadways and raised into the air during attempts to reproduce locally the blast of a weak dust explosion, the aim being to compare neutralization ratios of settled dust and of the same dust when raised into the air. A description of equipment used is given. Summary of results : there are sometimes substantial differences between settled dust and dust raised into the air, even where the regulation ratio of the settled dust is abided by; factors blamed are humidity, which plays a part in binding stonedust but not coaldust, and hidden dust not discernible through regulation measurements.

  Following this is a summary of the facilities we had to measure dust :

  . during settling;
  . once deposited;
  . when raised into the air.

These measurements allow the actual risk of a dust explosion to be assessed more precisely. Nevertheless, this research, which was undertaken initially by a French coalfield, must be seen as forming only one stage of a more detailed study on the dust explosion danger related to underground conditions. This was the object of an application for ECSC aid made in August 1980.

Notice to the reader

Traduction des termes : "empoussièrage" et "empoussièrement"

Ces 2 termes ont une signification différente.

L'empoussièrage est le poids (ou concentration) de poussière en suspension dans l'air; il est exprimé en mg/m^3 d'air.

L'empoussièrement est le poids de poussière qui se dépose sur une surface donnée par unité de temps; il est exprimé ici en mg/mètre de galerie/heure.

Pour éviter toute confusion, je propose les traductions suivantes :

empoussièrage : die Staubbelastung (D)
the dust concentration (G.B)

empoussièrement : die Staubablagerung (D)
the dust déposition (G.B)

COMPARATIVE STUDY OF FLAMMABLE DUST DURING DEPOSITION, DEPOSITED AND RAISED INTO THE AIR - R. Liberda

The above title covers two studies carried out in the Nord - Pas-de-Calais collieries, which differ greatly in origin, objectives and conclusions.

The first might be called a 'comparison of dust during deposition and when deposited' and the second a 'comparison of settled dust and dust raised into the air'.

I will deal with each of these two parts separately, then will attempt to combine them in a synthesis giving more space to the question of measuring flammable dust.

1. Comparison of dust during deposition and when deposited

This study stems from the introduction of the CPM3 (slide 1) instrument in France to measure the harmful dust concentration underground.

Briefly, the instrument functions as follows : the dust-laden air is drawn in at a constant rate of 50 l/mn (slide 2), and passes through a cyclone where dust particles greater than 5 µm settle; fine dust particles rise to the filter where they are collected, with the exception of very fine dust particles smaller than 0.5 µm, which pass through the filter and out of the instrument. After sampling is completed, the filter is taken out and weighed to determine the harmful dust concentration in the roadway. Large dust particles deposited in the cyclone, which are not covered by regulations, are disposed of.

All French collieries are now equipped with this instrument. Leaving aside the reason for which it was designed, i.e. to measure harmful dust concentrations, let us now look at the information it can provide.

From the distribution curve of the CPM3 (slide 3), it can be seen that only very fine dust particles less than 0.5 µm are not collected because they pass through the filter. Since this very fine dust only represents a very small part by weight of total dust likely to remain suspended in the air, the instrument may be assumed to collect practically all flammable dust passing through it.

Whence the idea of using the CPM3 to measure the total dust concentration of the atmosphere by analyzing the dust particles of 0.5 to 250 µm it collects.

Whence too the idea of using this instrument to determine the quantity of flammable dust deposited in roadways and perhaps the frequency with which stonedusting operations should be carried out.

Before a direct experiment to compare the CPM3 and other dust-measuring methods was undertaken, preliminary tests to adapt the device to this new use had to be carried out. I will confine my remarks to the most important test, which was to monitor the reliability of the instrument.

1.1 Monitoring the reliability of the instrument

This preliminary test therefore consisted in monitoring the reliability of the CPM3 by comparing the information provided over five days by several instruments placed side by side (slide 4); the findings appear on the following graph (slide 5). There is an average daily dispersion of 16 %, apparently due to the lack of uniformity, which is more-over perfectly normal, in the dust in a given section, and also perhaps to operator handling during cleaning of the instruments.

The dispersion might seem perfectly acceptable in view of the physical nature of the phenomenon being measured, but nevertheless it gave rise to some doubt as to the validity of future measurements.

At all events, it was decided at this stage to continue with the test.

1.2 Comparative tests with other measuring methods

Whe now come to the experiments proper which consisted in comparing dust concentrations given by the CPM3 with other measuring methods.

This series of experiments was lengthy and underwent several modifications as experience was gained; I will therefore only speak of the most significant tests and findings.

1.2.1 Comparison with suspended plates and measurement of stonedust ratios

The initial idea was to set up three measuring stations 50 m apart in a return airway (slide 6), comprising :

- 5 CPM3 more or less regularly spread over the roadway cross-section;
- 5 horizontal plates hung 2 m in front of each instrument,

and compare over a given period:

- the information provided by each CPM3 with that from its associated plate;
- the differences in the dust concentration recorded between stations with the variation in stonedust ratio in the same area.

Nevertheless, no correlation could be found between the CPM3 and the plates set out in this fashion, as witnessed by the wide cluster of points plotted (slide 7); the best conclusion that can be drawn is that there is a virtually exponential fall in dust concentration measured by the CPM3 as the distance from the face increases (slide 8).

Nor was it possible in any way to relate the differences in dust concentration recorded between stations to the variation in stonedust ratio - no doubt owing to insufficient precision in this type of sampling (carried out using a brush and spatula) for such a comparison.

In spite of this, the few positive facts noted during the test encouraged us to repeat it with a few variations.

1.2.2 Comparison with plates placed on the floor between two CPM3

This time (slide 9) there was only one CPM3 at each of the three measuring points, which previous tests had shown were enough to give the average dust concentration of the cross-section; plates were placed on the floor between stations.

The comparison related firstly to the difference in dust concentrations recorded by the stations, and secondly to the quantity of dust deposited on the plates over, the same period; the second figure was intended to give the dust deposition on the floor much more precisely than the stonedust ratio.

NB: while the dust deposited on the plates gave a correct indication of dust build-up on the floor, the dust on the roadway walls could not be determined by such a method.

So while it was impossible for the two measurements to be equal eachother, they could at least be compared by calculating their ratio and seeing whether it was constant.

The following graph (slide 10) gives the dust deposition expressed in mg/metre of roadway/hour given by the CPM3 between stations 1 and 2, 2 and 3 and 1 and 3 along the x-axis, and the dust deposition on the floor given by the plate placed between stations and expressed in the same units along the y-axis.

This gives us an average 34 % dust deposited on the floor and the rest on roadway walls.

However logical and encouraging this result might appear, the following remarks must be made:

- the dispersion in these ratios, with a standard deviation of 26 %, is significant, in spite of the rigorousness with which the test was conducted, in particular the continuous monitoring by the person responsible;
- the only relative reliability of the instrument and the lack of uniformity in the dust concentration in the roadway cross-section mentioned above are certainly reasons for this lack of precision; it must be

borne in mind that what is acceptable in assessing a harmful dust concentration whose cumulative effect (i.e. the danger threshold) is measured in decades is not so at all for flammable dust where the cumulative effect is measured in days, or even in shifts;

- in measuring the dust deposition in roadways, this instrument does not take account of dust conveyed other than through the air (e.g. by conveyors or machines), nor of local falls of dust. These factors may considerably affect the dust deposition in conveyor roads.
- furthermore, since the time for the next stonedusting operation depends on the amount of dust deposited, it can easily be shown that measuring neutralization ratios, according to French regulations, on the surface layer of dust deposits will require a new stonedusting operation before the instrument does;
- lastly, supposing that in spite of everything a stonedusting frequency can be worked out, this rate depends in the last analysis on the contraints imposed by operations, which mean that stonedusting can practically only be carried out on weekends.

For all these reasons, the CPM3 does not seem capable of providing reliable information on the dust risk level in roadways despite all the positive aspects which led to its being tested to this end.

Moreover, the dust risk depends on other factors, as will be seen in the second part of this paper. In conclusion, it should be noted that the CPM3 only measures dust during deposition, and that there is an important stage between this state and the state in which the dust, once deposited, may or may not form a cloud capable of transmitting an explosion; this may stand as the conclusion to the first part.

2. Comparison of settled dust and dust raised into the air

As explained in my introduction, this research was carried out independently of the previous project; I conducted it under the direction of Mr Augustin Coquide, whom I should like to thank for the energy and tenacity he showed.

This study follows on several unanswered questions arising after the Liévin catastrophe:

- how could a dust explosion be propagated in roadways where the neutralization ratio was above the regulation one?
- did that simply mean that the neutralization ratios laid down in French regulations should be queried, or did it imply ignorance of some dust explosion mechanisms on the part of research institutes and the industry in general?

It then occurred to researchers that regulations had always been based on trials carried out in experimental galleries; for consistency reasons, these trials always involved homogeneous mixtures of coal dust and inerts spread through-out the roadway.

It is perfectly obviously that such conditions have little in common with the actual situation in mine roadways. One need only note that coal dust settles almost continually, since it is a direct product of coal winning, whereas stonedusting takes little time and is generally carried out once a week; the dust deposit underground is thus a complex pile of coal and inerts. Added to this is the binding power of dampness which acts differently on coal and on stonedust. This abundantly demonstrates to what extent this state of affairs differs from conditions in experimental galleries.

It therefore seemed logical to find a way of showing the dust actually involved in an explosion; the basic idea was to attempt to reproduce locally the blast of a slow-moving explosion under conditions which did not present any danger underground, and study the dust raised into the air.

Two methods were used in all. The first consisted in directing a stream of air onto a surface of several dm^2 covered by an enclosure.

With the first type of apparatus (slide 11), the dust was raised by a tangential stream of air or nitrogen at a pressure of 50 m/s, or simply by the operator blowing at 10 m/s. The dust raised into the air was redeposited on slide-out shelves, collected with a brush (slide 12) and analyzed; this apparatus was made of transparent plexiglass and used mainly on the floor; each measurement took six minutes;

In the other sort of apparatus (slide 13), the surface onto which the stream of air was directed was circular and the dust raised into the air was deposited on a paper filter which was then removed, folded together with the dust it contained and sent to the laboratory (measuring time: one minute). The filter was burnt along with the dust and since the weight of its ash remains were known, the stonedust ratio was worked out with a maximum error of one percent.

The second method (slide 14) consisted in directing a stream of compressed air onto the roadway surfaces, at a tangential speed of the order of 50 m/s.

The dust was collected on plates suspended several metres downwind. Before each operation, the stonedust ratio of the settled dust was measured.

It would take too long to give all the quantitative findings; they point to the sometimes substantial differences between the stonedust ratio of a dust layer on the roadway and that of the same dust layer when disturbed by a stream of air.

The following observations arise from the findings as a whole: in roadways which are frequently subjected to intensive stonedusting using the CPOAC, the stonedust ratio of dust raised into the air is very close to that of the dust remaining; that can easily be explained by the fact that the stream of air raises dust below the surface where there is a lot of stonedust.

On the other hand, where a roadway is stonedusted less frequently and is subject to damp, the stonedust ratio of dust raised into the air are generally much lower than those of the dust remaining, though it has a correct regulation ratio;

the stream of air acts predominantly on the coal dust whereas the more hydrophilic stonedust tends to remain bound.

Thanks to these trials it was also observed that a stream of compressed air directed freely against, for example, the roadway walls showed the danger presented by coal dust hidden behind the support units, boards and crumbling surfaces which only a blast of air may dislodge.

Lastly, let us note that the process of blowing air inside an enclosure showed what weight of coal dust could be raised in the air per square meter of roadway, and this should be compared with the lower explosibility limit which is 50 g/m^3.

All these observations give us an idea of what a weak explosion may be, and why it has remained for so long a little-known phenomenon so difficult to foresee using traditional methods for measuring deposited dust.

Unfortunately I have only been able to give a cursory description of a very vast range of experiments, the results of which fill several reports without exhausting the topic.

This study could form part of a wider range of aids in the understanding of dust deposits; these may be divided into (slide 15):

- measuring dust during deposition, an example of which we saw with the CPM3;
- measuring deposited dust, which is practised according to regulations in almost all mining countries;
- measuring dust raised into the air, of which I have just spoken in the second part.

All this brings us closer and closer to an ever more precise assessment of the risk presented by dust should there be an explosion.

Nevertheless, however extensive this research might appear, it still remains only an introduction to the problem; critisism could rightly be levelled at it for the relatively small population of measurements (about 60) for dust raised into the air.

These initial observations underground should therefore be confirmed by a larger series of measurements.

Supposing this was done, the basic problem remains the same, i.e.: will the explosion be propagated or not, bearing in mind that this depends also on other factors such as:

- the effect of the flame's heat in drying, splitting up and then volatilizing dust initially damp and not likely to be raised into the air;
- the conveyance of dust by a blast far from its original position;
- the influence of 'channels' which allow an explosion to be transmitted without its taking up the whole cross-section of the roadway.
- the answer to these questions could be found this time in an experimental gallery. Here weak explosions could be carried out by reproducing - and this is vital - the dust deposition conditions underground by introducing:
- an air current;
- a deposit of dust with dust concentration ratings comparable with those of our workings;
- stonedusting carried out with the same devices as underground;
- a degree of humidity in the air so that it plays its part in the formation and binding of the dust that has collected.

These experiments would then show how the various parameters listed were responsible for the propagation of an explosion; measurements of dust deposited and raised into the air would be carried out before ignition; these tests could also include the effect of safety barriers on weak explosions under such conditions.

As can be seen, research of this scope is beyond the means of our collieries; I would go as far as to say that technically and financially this problem does not only concern the Charbonnages de France but involves the whole industry.

The application for ECSC assistance submitted in August 1980 by the Charbonnages de France was made in this spirit.

Bearing in mind that after the Liévin disaster (which all the same brought home the importance of weak dust explosions), other disasters of the same type have occurred in Europe, it is imperative to know what precautions would finally provide lasting protection for the miner.

Such experimental research would in my opinion, be of the greatest advantage for the collective safety of the industry.

R. LIBERDA

SLIDES TO GO WITH THE PAPER

COMPARATIVE STUDY OF FLAMMABLE DUST

DURING DEPOSITION, DEPOSITED AND

RAISED INTO THE AIR

Fig. 1. CPM3 type dust sampler

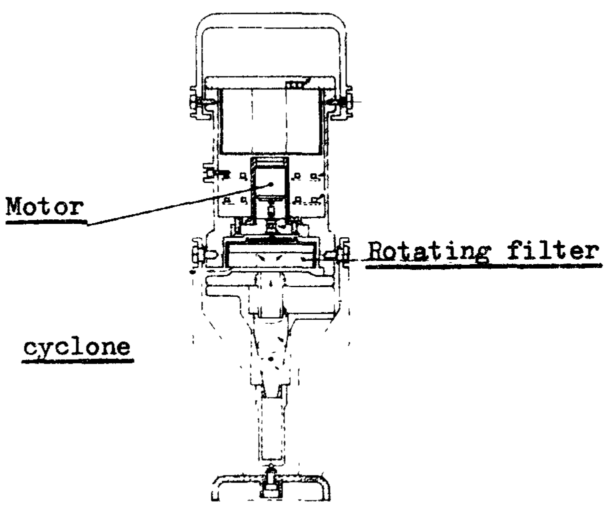


Fig. 2. CPM3 sampler: principle of operation

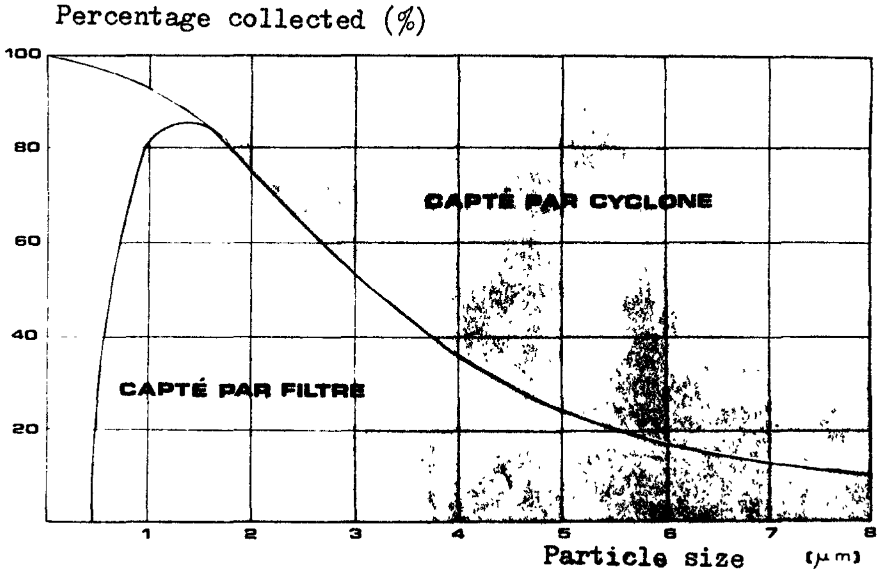


Fig. 3 CPM3 partition curve

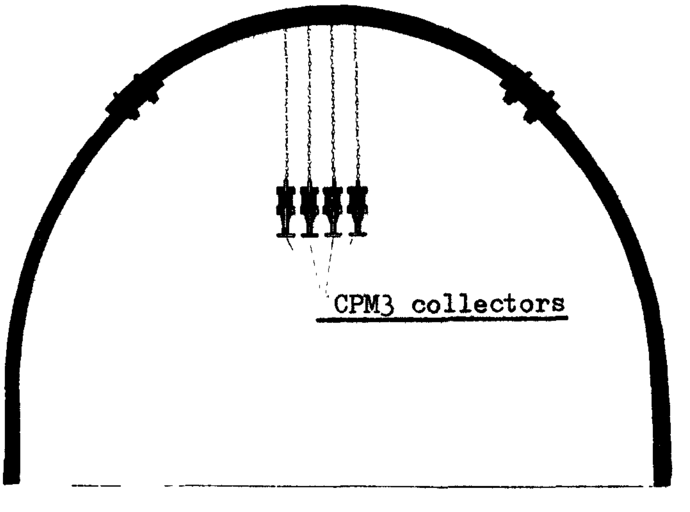


Fig. 4 Monitoring the reliability of the CPM3: arrangement of units in roadway

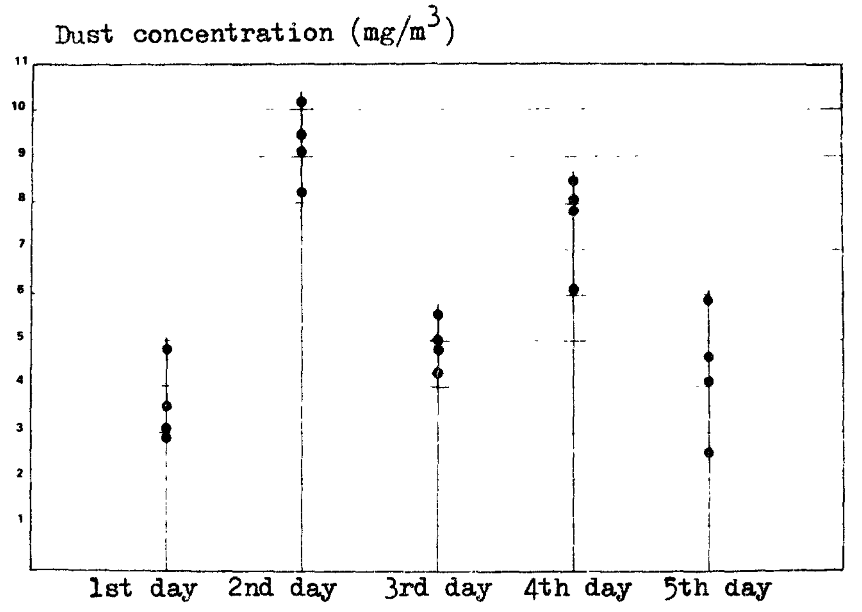


Fig. 5 Monitoring the reliability of the CPM3: dispersion of findings over five days' testing

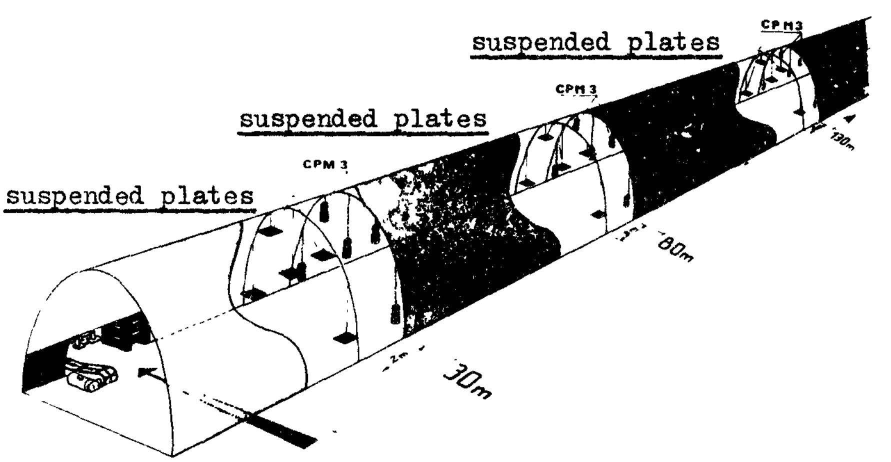


Fig. 6 Comparing findings from CPM3 and suspended plates: arrangement of units in roadway

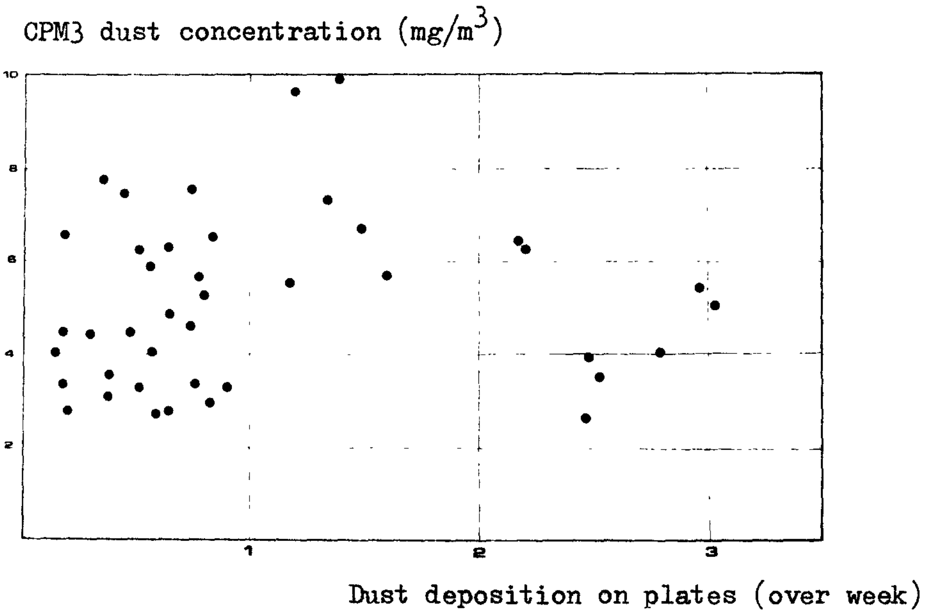


Fig. 7 Comparing findings from CPM3 and suspended plates: correlation between the two methods of measurement

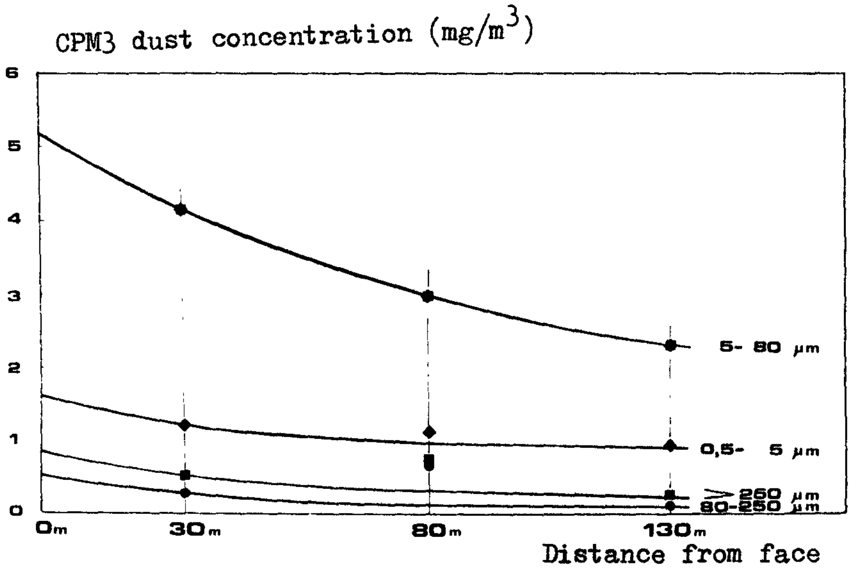


Fig. 8 Comparing from CPM3 and suspended plates: Fall in CPM3 dust concentration readings as distance from face increases

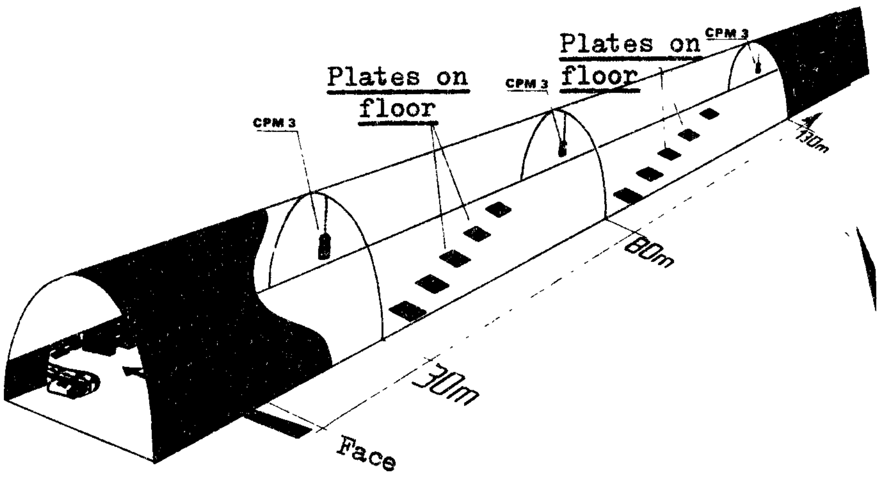


Fig. 9 Comparing findings from CPM3 and plates on floor: arrangement of units in roadway

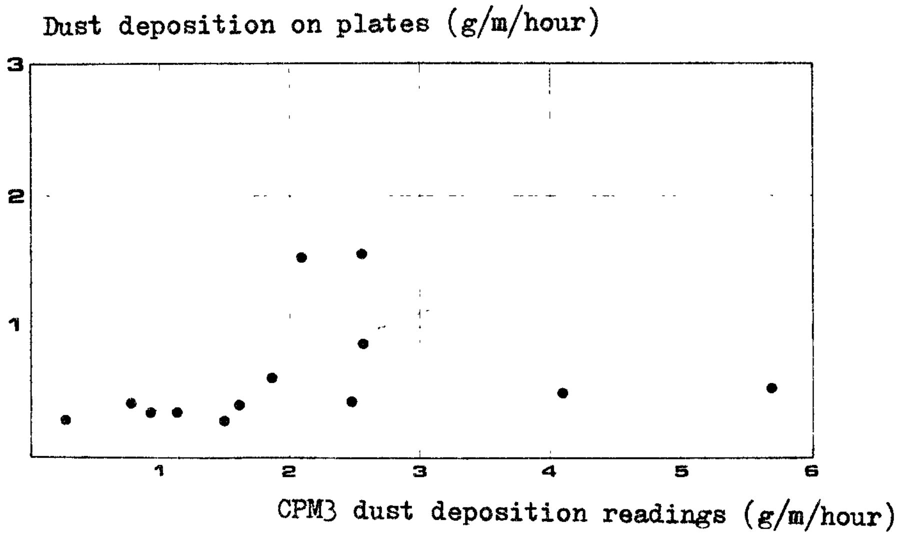


Fig. 10 Comparing findings from CPM3 and plates on floor: correlation between the two measuring methods

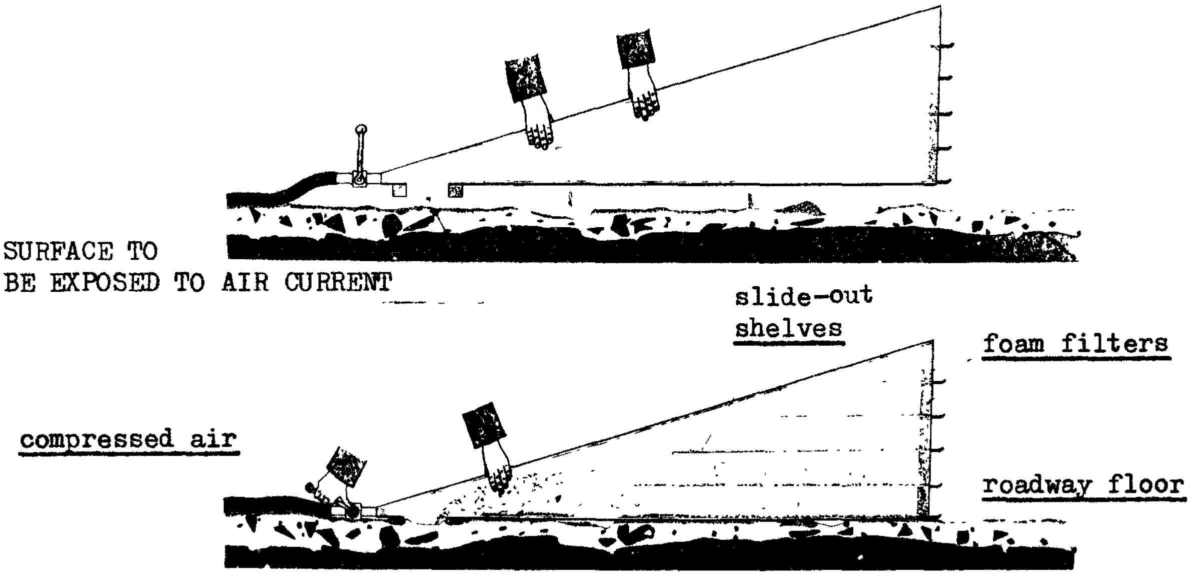


Fig. 11 Enclosure with slide-out shelves for measuring dust deposition:
blowing air against the roadway floor

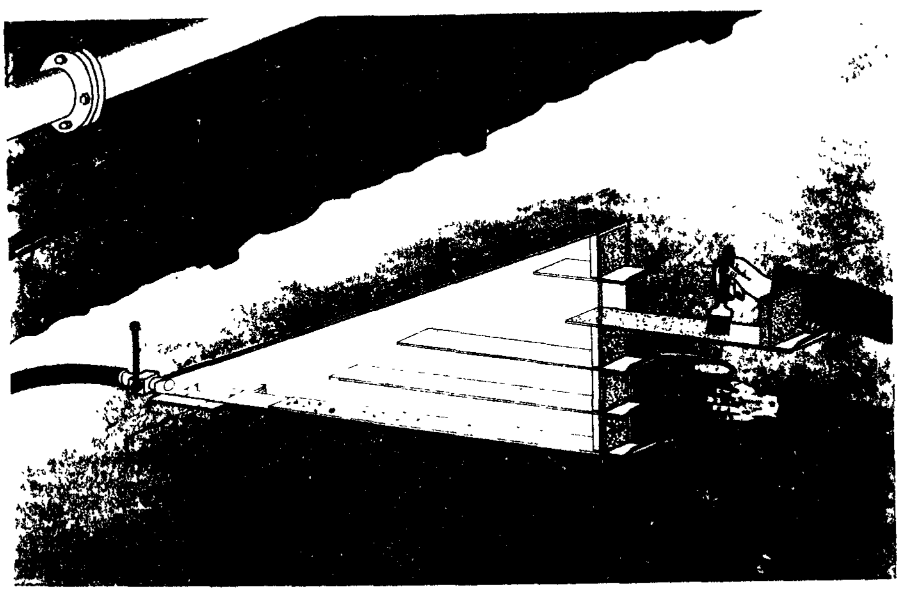


Fig. 12 Enclosure with slide-out shelves for measuring dust deposition:
collecting the dust raised into the air

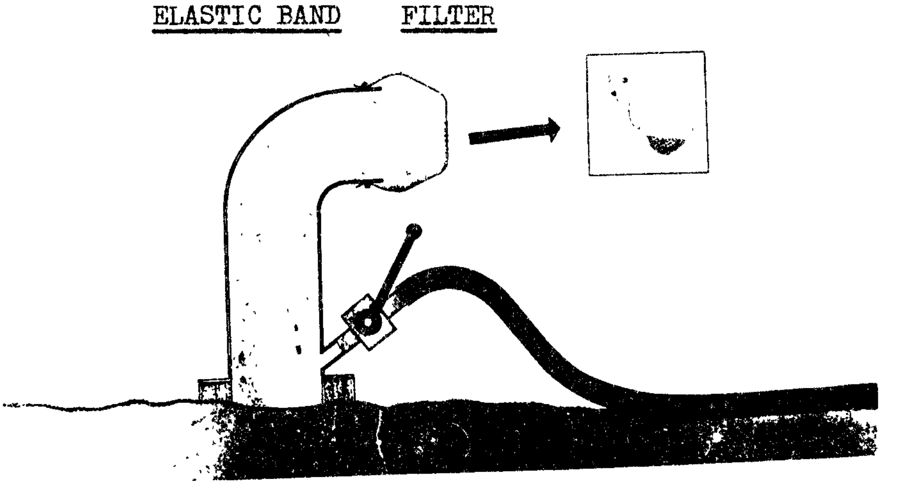


Fig. 13 Enclosure with filter for measuring dust raised into the air

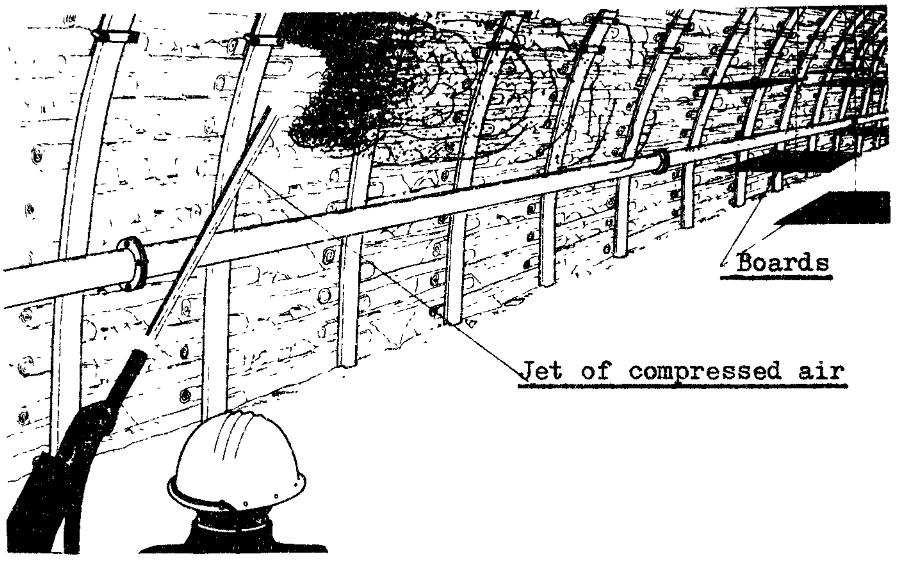


Fig. 14 Blowing air freely around the roadway cross-section

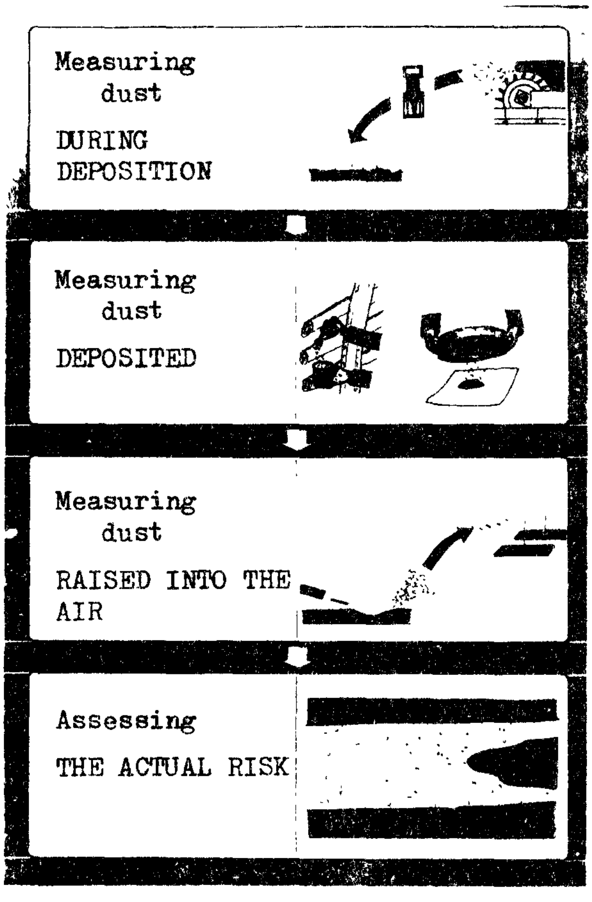


Fig. 15 Summary of dust-measuring methods

Summary of the paper entitled
'Activities in the field of multiple explosions'
for the Information Conference on
'Flammable Dusts' to be held in Luxembourg on 5.11.1981,
presented by Dr H. Meerbach
of the VERSUCHSGRUBENGESELLSCHAFT MBH

There is always a risk of explosions when open or concealed mine fires occur. They may take the form of multiple explosions, with intervals (between the explosions of several minutes to several hours) depending on the ventilation conditions.

The mine rescue teams should be protected by the existing explosion barriers if possible whilst carrying out the stopping-off operations. In the event of fires, other means are also generally employed to suppress explosions. The effects of explosions can be kept within limits in most cases by the use of rapidly erected barriers, called 'rapid barriers' in Germany, consisting of suspended water troughs. Recently, the risk of explosions has been greatly reduced, if not completely eliminated, in the Federal Republic of Germany by the increased injection of nitrogen into fire areas.

Nevertheless, it was considered desirable to examine the protective influence, in multiple explosions, of the stone dust and water trough barriers currently in use.

In order to conduct multiple explosion tests with explosions at intervals of less than 24 hours, appropriate mining and measuring arrangements had to be made in the explosion gallery network of Versuchsgrube Tremonia to allow a secondary explosion to be ignited after the primary explosion without the involvement of additional underground operations. Special testing arrangements made it possible for multiple explosions to be produced at minimum intervals of 20 minutes.

The effectiveness of the explosion barriers against the secondary explosion depended more or less on their effectiveness against the primary explosion. The more effective they were in suppressing the primary explosion, the less effective they were in neutralizing the secondary one. The character of the secondary explosion mainly depended on the combustible material left over from the primary explosion. The inert material which had already been ejected had hardly any dampening effect, or none at all, on the secondary explosion.

Further explosion tests are to be carried out as part of a research project of the Commission of the European Communities at the Versuchsgrube Tremonia in order to examine means of suppressing a secondary or multiple explosion.

'Activities in the field of multiple explosions'
for the Information Conference on
'Flammable Dusts' to be held in Luxembourg on 5.11.1981,
presented by Dr H. Meerbach
of the VERSUCHSGRUBENGESELLSCHAFT MBH

The problems caused by the possibility of double or multiple explosions were discussed in paper B 3 which I presented at the International Conference on Mine Safety in Cavtat in 1979. I apologize to those who have studied the papers of that Conference because parts of them will be repeated today. The problems, however, have not lost their relevance : the basic situation has emained unchanged. As an introduction, I would like to make a few comments on how multiple explosions can occur, and go into detail on the type of protection aimed at in the present work.

Explosion risks in mine fires

When an open mine fire occurs, an explosion can generally be expected to develop. The risk of an explosion occurring in the event of a concealed mine fire cannot be precluded from the outset, either. The explosive medium may be a methane-air mixture, which can become more concentrated in the event of a fire. Gas continues to be emitted at more or less the same rate, at least at the initial stage of the fire, whereas the ventilation is reduced, in some cases drastically, as a result either of the fire itself or of the steps taken to extinguish it. An explosive mixture can also be created when combustible gases form through a shortage of oxygen in the fire itself, and are then diluted when they mix with fresh ventilating air containing oxygen. Both methane and fume explosions can trigger off a coal dust explosion. Since gas and fume emission continue over a long period, it is definitely conceivable that the process by which an explosive mixture forms can recur several times in succession. The constant presence of an ignition source - the fire - means that there is a risk of several explosions occurring successively. Such multiple explosions are frequently observed in fires; the interval between explosions depends on the ventilation conditions and ranges from several minutes to several hours or days.

Protection by means of existing explosion barriers

To begin with, it may be assumed that the mine rescue teams involved in firefighting are protected from this type of explosion by existing barriers. Mr Jenderek spoke about the barrier system used in the Federal Republic of Germany this morning and therefore I need not repeat that information.

It can be estimated that about 10 complete barriers must be located in the air intake and return air roadways leading to a production district. The number of barriers is much higher, of course, if distance are very long.

There should always be at least one of these barriers between the fire and the stopping-off point.

Further measures in the event of fires

Nevertheless, there are other means available for the suppression of explosions during stopping-off operations, such as the use of special 'rapid barriers'. These were developed several years ago at the Versuchsgrube Tremonia as lightweight barriers which can be installed by the mines rescue team with relatively little effort and time. This type of barrier provides effective protection against explosions, even with a small amount of water, because manriding and transport operations no longer have to be taken into account when it is installed in the roadway. As I shall mention later, this special design is not really necessary at all and can be simplified considerably. In recent times, the neutralization of fires with nitrogen has come into increasing use in the Federal Republic of Germany. Apart from dampening the fire, this method is a very rapid means of reducing the explosion risk substantially, or even eliminating it completely.

In spite of the fairly positive results provided by the latter possibility in particular, the German mining authorities considered it desirable to examine what protection the existing explosion barriers could provide against a secondary explosion after they had been actuated in a primary explosion which they had succeeded in containing. Furthermore, it was considered desirable to seek ways of increasing the protection provided by normal water trough or stone dust barriers against multiple explosions.

I shall indicate the test results in a moment, and to help you understand these more clearly, I think it is necessary to give a brief description of the experimental conditions.

At the Versuchsgrube Tremonia, like all other research institutes dealing with test explosions, we normally try to produce each explosion in conditions which can be reproduced as closely as possible. As a result, the explosion gallery has to be cleaned after each test as well as possible and, before the next is carried out, coal dust, in some cases mixed with stone dust, has to be scattered in precisely defined quantities and according to specific procedures. This general method had to be dispensed with in the tests involving double explosions.

Since the taking of measurements at the various points in the explosion gallery network at the Versuchsgrube Tremonia and the transfer of the measurements to the measuring station has been fully electronic processes for several years, no manual activities or checking have to be carried out between explosions. The roadways are also protected from the mechanical effects of explosions so that in normal cases, i.e. during medium explosions, there is no likelihood of damage occurring which would make repair work necessary.

Since explosions can only be carried out when there is no-one underground, the tests can only be conducted during afternoon shifts because the morning and evening shifts are devoted to other work. In order to start the ventilation and check the effects and progress of explosions, a mines rescue team has to travel through the gallery area after each explosion test.

A decisive item in the planning of the tests was the interval between the explosions. An interval of 24 hours involved no rearrangements or problems because this was the normal interval between test explosions. In this case, it was only necessary to dispense with the normal cleaning of the roadway.

Since an interval of 24 hours was much longer than those occurring in practice, steps were taken to reduce the period substantially. A new primer cartridge was installed by the mines rescue team during the normal inspection after the explosion. The cartridge consisted of a charge of 2.5 kg of granulated blackpowder in a W mortar (a steel container with a W-shaped axial section) and 3 to 6 pressure cylinders placed next to the wall near the charge, from each of which 5 kg of coal dust was ejected 1 s prior to ignition of the blackpowder. The time taken by the mine rescue service meant that explosions could be carried out at intervals of about two hours.

To reduce the interval between two explosions even further, special preparations had to be made. Since the roadway could no longer be inspected between the two explosions, the main ventilation current had to be maintained in the course of the explosions as well. This generally does not present any problems and previous test series have shown that the course of an explosion does not depend on the ventilation in the explosion area. Since the pressure of the explosions could be felt in the entire Versuchsgrube Tremonia mine area, the ventilation structures guiding the air current had to be made explosion-proof. Sufficient experience had also been gathered on this subject, too.

A more complex problem was that of protecting the primer cartridge for the second explosion, which had to be placed and made live before the first explosion, from the effects of the first explosion so that it remained fully intact for the second explosion. This was relatively simple in the case of the steel cylinders for ejecting the coal dust, since it was possible to fix them securely enough to the supports to withstand the pressure, which is not very strong at the source of the explosion in any case. The ignition cables, which had to withstand the effects of the flames from the first explosion, were more problematical. The solution consisted in providing them with silicone rubber insulation. The most difficult problem appeared to be the securing of the actual primer cartridge, i.e. the blackpowder ignition charge. Fortunately, however, a blackpowder charge placed in the borehole of a steel mortar was found to withstand the flame from an explosion without damage, so that it could be used for ignition the second explosion.

The interval between the two explosions now only depended on the flushing of the explosion gallery with the ventilation current.

This operation took about twenty minutes and the removal of the explosion fumes was monitored by CO and CO_2 measuring units, which were placed in the return airstream and transmitted their readings to the surface.

It is not possible to provide any further details of the test series in this talk. The information I have already given you is, however, sufficient to give you an insight into the experimental problems surrounding the work. I shall now try to give you a clear summary of the results obtained so far.

The first result is not connected with the barrier's extinguishing capacity but is nevertheless characteristically significant for multiple explosions. For single explosions in underground conditions, a coal dust concentration of about 300 g/m^3, irrespective of the type of stone dust selected for neutralization, has proved to be the optimum value for the development of an explosion. Since during the tests a second explosion had to be made possible, for which combustible material had to remain available, it was decided to scatter 500 g of coal dust per m^3 of gallery area, mixed with 200 g of stonedust. This quantity proved insufficient and the effect of the secondary explosion was hardly stronger than that of the primer cartridge. Only when the amount of coal dust scattered was increased to 700 g/m^3 and a more powerful primer cartridge was used was the secondary explosion able to develop into a full progressive explosion.

As far as the barriers effectiveness is concerned, it can generally be said that the neutralizing effect of all barriers against the secondary explosions was weaker, the more effectively they suppressed the primary explosion. When the results are examined in detail, we find the following:

<u>stone-dust barriers</u> and, in some tests, <u>water trough barriers with specific additives to the water</u>, occasionally failed to function

even during the primary explosions. The flames from these explosions then filled a large section of the roadways and the combustible material was almost entirely consumed. Consequently, the secondary explosion was weak and flames were only short. When highly effective water-trough barriers, and especially wide-action barriers were tested, the primary explosions were suppressed at the first groups of throughs. The flames were short and little combustible material was consumed; the secondary explosion was able to develop substantially in the combustible material that remained and long flames were produced. An interesting point is that this result did not vary according to the different intervals between explosions mentioned at the beginning of my talk.

In the attempt to find barriers which were more effective against secondary explosions, additives were put into the suppressant water to begin with. These consisted of either a wetting agent to increase the water's capacity to wet the coal dust and prevent it from circulating, or of a substitute for water in the form of a calcium chloride solution. The wetting additives had no effect. In the case of the standing water troughs, the use of a calcium chloride solution had a negative effect, as already mentioned, in that the barriers did not operate properly during the primary explosions. This is most probably the result of an increase in the density of the suppressant fluid, and consequently, an increase in the weight of the filled troughs. The suspended water troughs were not affected in this way, but the neutralizing effect of the secondary explosion was not increased either. Triggered barriers consisting of water troughs, whose content was ejected by explosives, were used but were also unsuccessful. The design of a triggered barrier employing suppressant dust which is blasted out of steel cylinders will be described in the next paper given by Mr Faber. Unfortunately, it has not yet been possible to investigate this possibility in test explosions.

Secondary explosions were suppressed successfully by water troughs placed on the floor and filled by the mine rescue service in an operation lasting only a few minutes. This positive result has already had repercussions in the West German coalmining industry in that during emergencies, water troughs are placed on the floor instead of using the high-speed barriers already mentioned, which consist of rather complicated suspended troughs. Nevertheless, this method cannot be considered satisfactory for protection from secondary explosions because it involves the entry of the mine rescue team in the part of the mine where there is a risk of explosions.

Tests so far show, therefore, that it has not been possible to redesign conventional barriers by simple and inexpensive means to make them effective in neutralizing a secondary explosion. Apart from tests to be carried out with the Bergbau-Versuchsstrecke triggered barrier system in double explosions, intensive studies of other possibilities are to be conducted in a current research project. Unfortunately, however, a suitable barrier system is expected to be rather more complicated and expensive than the explosion barriers employed so far.

Multiple Suppression System for Triggered Barriers

M. Faber

Bergbau-Versuchsstrecke

The problems associated with multiple explosions and their causes have already been examined in detail by Dr Meerbach, and therefore this study can be confined to a description of how such explosions can be successfully suppressed by a newly developed system. It is automatically assumed that the mechanical components of the suppression system used are designed to resist the stresses to be expected from explosions and remain intact.

Bergbau-Versuchsstrecke's newly developed system for the suppression of multiple explosions is based on the BVS triggered barrier system which operates by rapid registration of the ultraviolet radiation from flames with a detector and transmission of the signal to an evaluation unit; the latter causes suppressant to be released from containers (V = 12,3 l, filled with 8 kg suppressant powder under 120 bars of pressure from nitrogen).

The general mode of operation of this new suppression system is explained below by way of a highly simplified description of a dual suppression system equipped with two sensors which is already available.

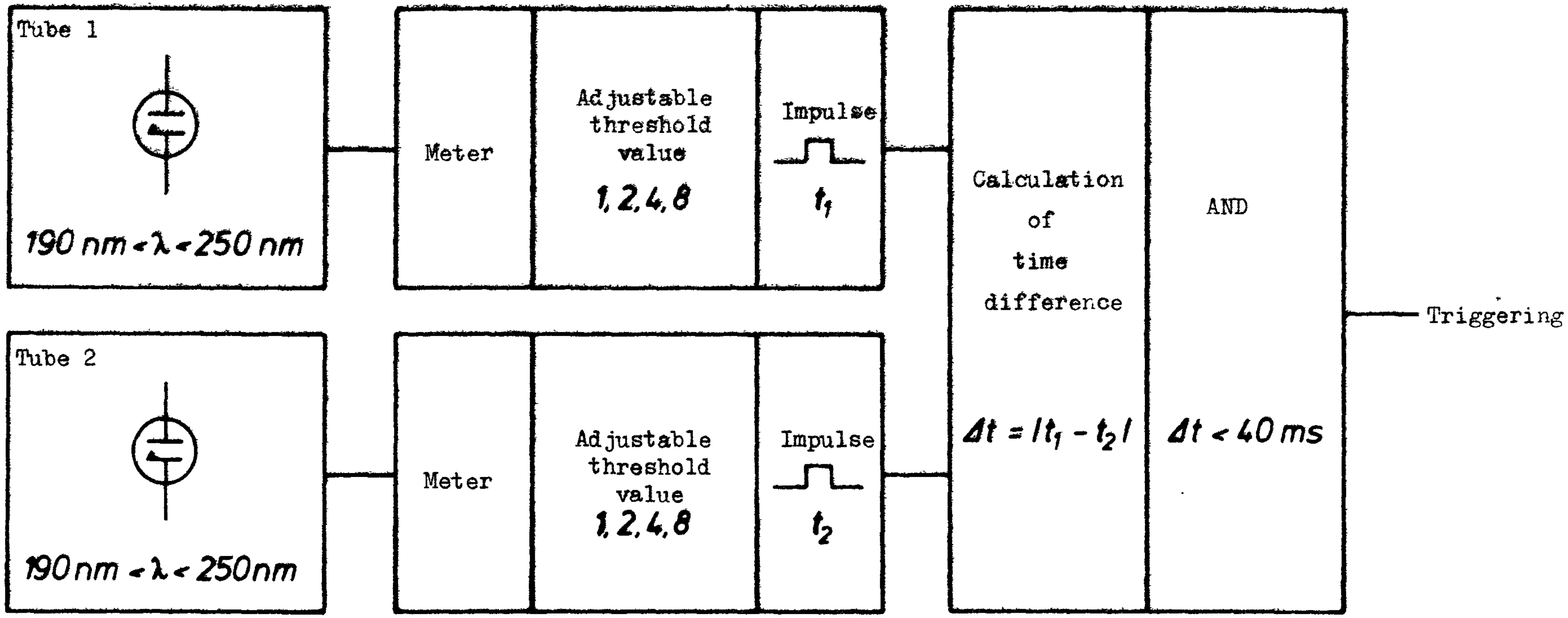
The flames are detected in each sensor by two selective detection tubes which are sensitive only to ultraviolet radiation from naked flames and sparks from the wavelength range of 190 nm $< \lambda <$ 250 nm and not to light from other sources such as sunlight, daylight or artificial lighting (e.g. miners' lamps). To provide a further guarantee that the sensor responds only to naked flames and not to individual sparks, the monitoring ranges of the two tubes are selected so that they do not overlap. The output impulses of each tube are transmitted to a meter which is connected to a threshold controller. When the set threshold is exceeded, an output impulse is emitted. In a time subtraction stage, the output impulses of the two tubes are checked for their timing and are AND-linked only in the event of a time correlation of $\Delta t < 40$ ms. It is this link signal which constitutes the triggering (detection) impulse of the individual sensor, causing the barrier to be actuated. The triggering impulses of the (two) connected sensors are transmitted to the evaluation unit and passed through an OR-link stage, to ensure that each sensor can actuate the barrier on its own.

The first actuation after the triggered barrier is put into operation then passes through an amplification circuit to actuate Barrier 1. At the same time, a time stage is started. After an adjustable waiting period, which is currently set at approximately 30 s, a further triggered impulse arriving from the OR-stage automatically passes through an AND-stage and amplification circuit to actuate Barrier 2. The circuit is also designed so that after triggering has occured, the equipment automatically tests itself and any parts of the barrier which may have been damaged in spite of their mechanical protection are automatically switched off.

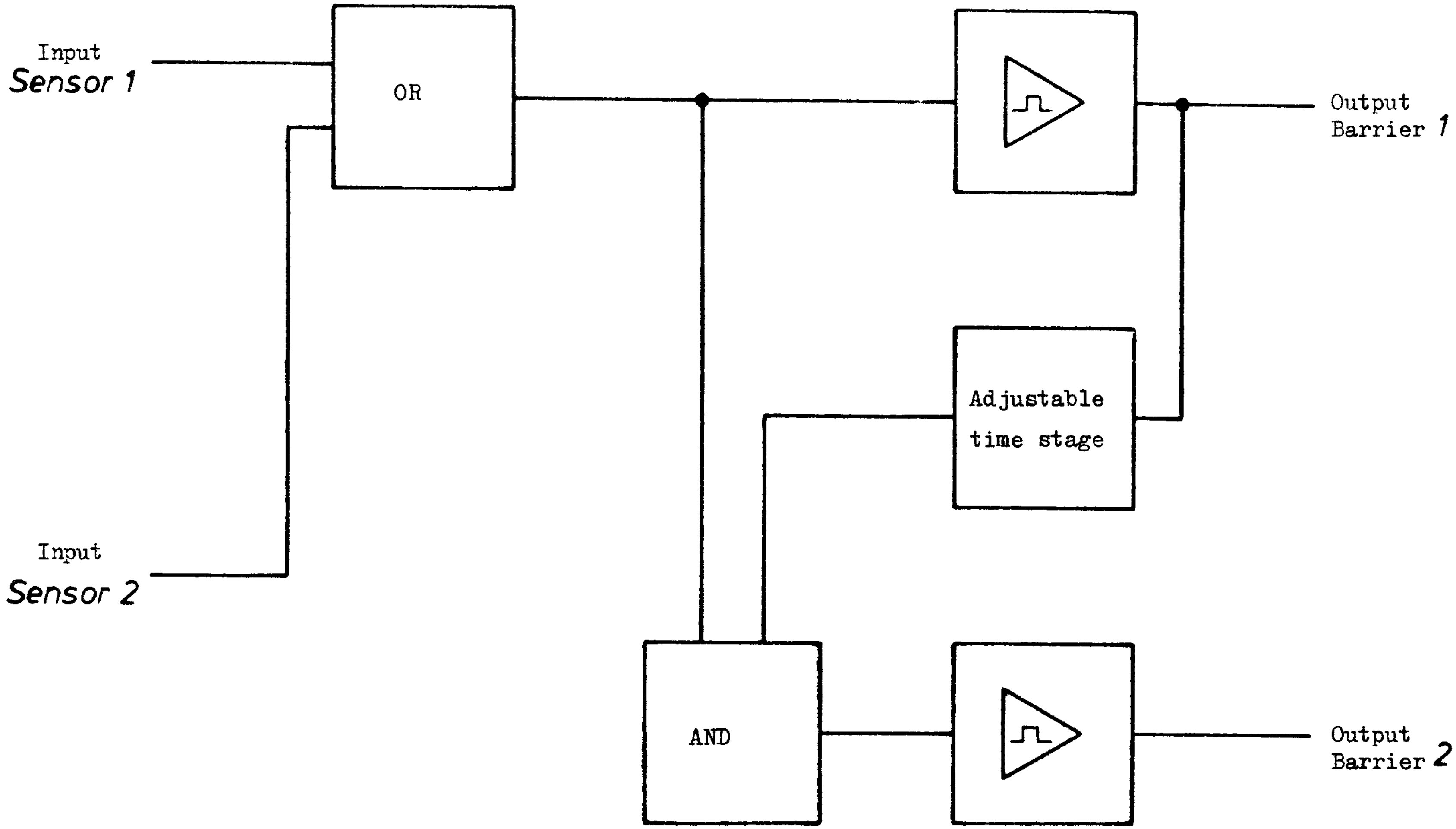
If a sensor does not function during the standby phase, which can be extended to $\geq$ 72 h with an emergency power battery, it is automatically switched off and the equipment continues to function with the other sensor only. If the suppressant containers of Barrier 1 become inoperative (e.g. as a result of a cable fracture), the quantity of suppressant which is put out of action is automatically made up from the amount reserved for Barrier 2. There is therefore always enough suppressant available for the first suppression. The automatic switch-over and the above-mentioned defects are of course displayed by remote-controlled indicator and the equipment's readiness for operation is also signalled by an appropriate indicator.

The electronic components, which have been developed from the latest techniques (C-MOS) and are of modular design, have been perfected and adapted to the problems concerned. With them, the dual suppression system can be extended almost without restriction to form a general multiple suppression system. There is therefore no problem in using n number of sensors for detection and actuating m number of barriers with only one evaluation unit. The regular self-monitoring of all components and automatic cyclic testing of the sensors keep the equipment constantly ready for operation over its entire installed capacity range. Defective parts are automatically switched off and any reduction in capacity is made up by suppressant "brought forward from the rear".

This report is therefore intended to illustrate how the mobile triggered barrier system already presented by Dr Scholl is able, with controlled distribution of the total quantity of suppressant available (50 suppressant containers) and with this newly developed control unit, to provide more effective protection from double explosions, e.g. when the rescue service is carrying out stopping-off operations.



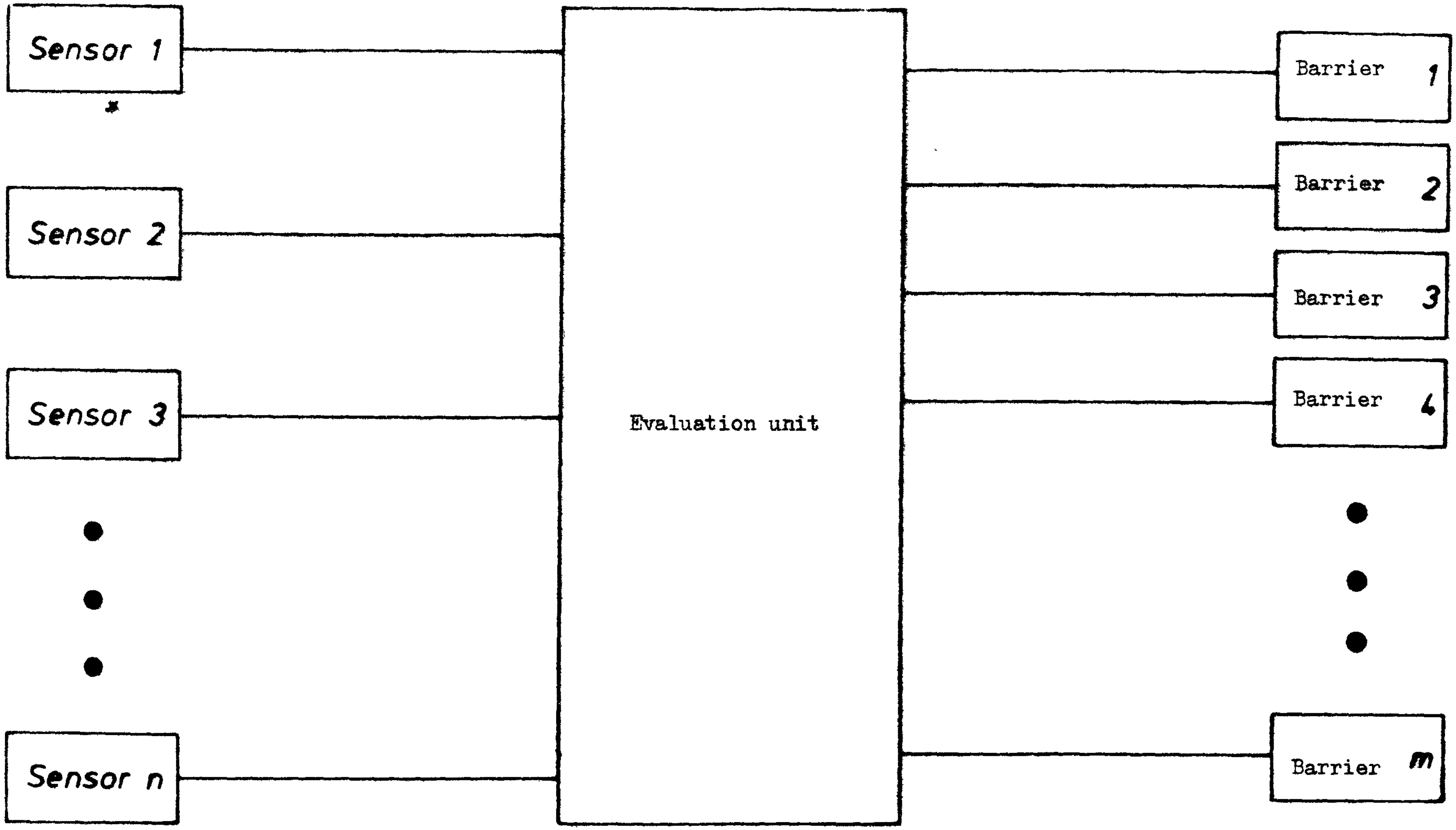
BVS	Sensor (schematic arrangement)	4642



BVS

Evaluation unit for dual suppression system (schematic arrangement)

4643



BVS	Basic extension capacity of a multiple suppression system for triggered barriers	4644

PREVENTION OF WEAK DUST EXPLOSIONS

M. Giltaire and J. Winter

Centre d'Etudes et de Recherches des Charbonnages de France

SUMMARY

There is no need to stress the advisability of attempting to prevent any local ignition of firedamp or dust from leading to the propagation of a dust explosion, and should this happen, trying to halt the explosion as close as possible to its starting point.

Neutralizing dust by stonedusting properly and on a permanent basis is quite often impossible in places where coal dust is likely to settle continually and in substantial quantities (e.g. in sections of roadways near faces). Wetting the dust may be considered in such cases to make neutralization more effective and tests are being carried out at present at the CERCHAR (Centre d'Etudes et de Recherches des Charbonnages de France) to evaluate the increased safety this may provide.

It was observed, for instance, that in a gallery of approximately 10 m^2 cross-section a dust deposit made up of a uniform mixture of 6 to 12 % water and fine coal dust with a natural ash content of 47 % did not propagate a dust explosion initiated by an explosive charge in a cloud of coal dust raised into the air.

In the same gallery, with more dangerous coal (volatile matter index 23 %, ash content on a dry basis 6.4 %) and under the same conditions as before, a 12 % moisture content in the dust deposit may be considered as effective in preventing an explosion as a solid inert content of 50 %.

Tests were undertaken in a metal surface gallery with a 2.5 m^2 cross section and 140 m long with coal of high volatile matter content, approaching 40 %, using an initiation source made

up of a cloud of 28 m^3 of firedamp ignited by 300 g of black powder in a mortar. The tests were designed to discover the percentage of calcareous dust needed to prevent the propagation of explosions or various percentages of water added to coal calcareous dust mixtures.

In a graph showing the percentage of solid inerts plus the percentage natural moisture of the coal along the x-axis, and the percentage of water added along the y-axis, the areas corresponding to propagation and non-propagation of explosions are delimited by a straight line whose slope is of the order of - 0.5. As a first approximation, with uniform mixtures of coal, calcareous dust and water such as these, a decrease of 2 % in the solid inerts may therefore be compensated by an increase of 1 % in the water.

Another means of preventing of a dust explosion consists in installing water barriers, the value of which was demonstrated in particular during tests in the Tremonia experimental mine. Nevertheless, safety-barriers of any type are known to fail if the explosion is a weak one; furthermore, mining contraints mean that water troughs cannot always be set up in conditions of maximum effectiveness.

Therefore, in order to reply to many questions from mine owners, and allow them to see the evidence with their own eyes, we felt it was worthwhile to test wide-action barriers in weak explosions to demonstrate the relative importance to be given to recommendations on installation.

In these tests, which were carried out in a gallery of approximately 10 m^2 cross-section, the wide-action water barriers were made up of four rows of one or two 80-litre troughs set 20 metres apart and placed at 35, 55, 75 and 95 metres from the end of the gallery. The explosion flame travelled at a velocity of the order of 60 to 90 m/s in the safety barrier area.

As a result of these tests, the following recommendations, in order of increasing importance, may be given in order to achieve maximum effectiveness with wide-action water barriers:

- troughs which are inserted into the supporting framework are slightly more effective than troughs which are simply placed on the supports;

- troughs placed one behind an other in a line parallel with the roadway axis must be at least 1.2 m apart;

- troughs should not be placed behind props;

- troughs should not be placed against the roadway roof - at least if it is more than 2 to 3 m high - and they should not be placed on other troughs;

- trough frameworks or supports should be of such a design that troughs cannot be rocked or displaced before being broken up;

- troughs must have their broad sides at right angles to the roadway axis.

PREVENTION OF WEAK DUST EXPLOSIONS

M. Giltaire and J. Winter

Centre d'Etudes et de Recherches des Charbonnages de France

- - -

The disaster which saddened the French mining industry in late 1974 obviously had direct repercussions on the industry's programme of research into dust explosions.

This particular dust explosion drew attention to the difficulties encountered in monitoring the neutralization of a dust deposit, an even more complicated problem when the deposit is damp, and Mr Liberda has rightly mentioned the many questions which might be raised in this connection.

It should also be pointed out that while the explosion unfortunately affected a very extensive area it can not be called a very violent one in view of its mechanical effects.

Measures to eliminate accumulations of firedamp (and as a result the main cause of violent explosions) and to prevent dust from being raised into the air and burning mean that in practice, once a dust explosion starts, the probability of its being fairly weak is high, at least at its point of origin.

An example of such a situation is provided by the sections of roadway near a face, where the build-up of dust may be substantial but the lack of space due to the presence of workers and equipment means that the sections cannot be neutralized as frequently and effectively as they should. Here, neutralization using water may perhaps be a worthwhile solution but we consider it important to look into its limitations.

In such areas as well as in other mine workings, the same factors or natural conditions such as a narrow cross-section, a steep slope, etc. may also make it difficult to install safety barriers under optimum conditions ensuring maximum effectiveness.

Therefore, in order to reply to many questions from mine owners - and allow them to see the evidence with their own eyes - we felt it was worthwhile to safety barriers in weak explosions to show up the relative value to be given to some recommendations on the installation of safety barriers, especially wide-action water barriers.

A - THE USE OF WATER TO NEUTRALIZE DUST DEPOSITS WITH AN INSUFFICIENT STONEDUST RATIO.

The research carried out by Cybulski showed that dust explosions did not spread when a sufficient quantity of water was added to mixtures of coal and calcareous dust. He discovered that the relationship between total water content and solid inerts contents which allows the areas of propagation and non-propagation to be delimited depended greatly on the violence of the source of ignition.

The tests described by Cybulski were carried out with coal with a high volatile matter content and a substantial amount of absorbed water (about 10 %). It therefore seemed worthwhile to assess the effect of the moisture with coal of varying characteristics.

After some tests in a gallery with a large cross-section (in our Montlaville quarry), we undertook more systematic tests in our 2.5 m^2 cross-section metal gallery.

1. Tests in the Montlaville gallery with coal dust only.

1.1. Test conditions.

1.1.1. Gallery.

The Montlaville gallery is 145 m long. The cross-section is trapezoidal and varies between 8 and 12 m^2. The roof is bolted.

1.1.2. Source of ignition.

Tests were carried out with an ignition source which may be described as moderately violent. This was 8 kg Montrambert coal dust placed in a pile at the end of the gallery, raised into the air by 10 g of explosive and ignited by 300 g rock explosive. Furthermore, 4 cross supports were placed between 5 and 10 m from the end and each bore 8 kg of Montrambert coaldust.

1.1.3. Dust deposit.

The deposit extended from 5 to 120 m from the end of the gallery. It was spread in such a way as to give an average concentration of 300 to 400 g/m^3 assuming that all the dust was raised into the air and spread uniformly around the roadway during the explosion.

The dust was deposited either only on the floor, or partly on the floor and partly on 11 boards balanced across the gallery 2 m high and at regular distances between 20 and 120 m. Each plank bore 8 kg of dust and was intended to help produce a cloud of dust throughout the gallery cross-section.

For these tests, two types of coal were used:

- coal from the Six Sillons seam, Lens (volatile matter index on a d.a.f. basis: 27.5 %; ash in dry state: 46.8 %; 60 % passing through a sieve with a 80 μm mesh);

- coal from Montrambert (volatile matter index on a d.a.f. basis: 22.9 %; ash in dry state 8.4 %; 60 % passing trough a sieve with a 80 μm mesh).

Immediately before it was placed in the floor or the supports, the dust was wetted in a totating cement mixer containing 40 to 50 kg coal and water mixture.

Samples were taken at four points in the gallery to measure the moisture content after the dust was deposited.

1.2. Results of tests.

1.2.1. Lens Coal (46.8 % inerts in dry state)

With dry dust placed on the floor and boards, the flame once extended outside the gallery (test 860) and once as far as 110 metres (test 863). The explosion spread at fairly low speeds, of the order of 50 m/s. The maximum explosion pressures 5 metres from the end were of the order of 0.22 bar ('static' pressures).

Once the moisture content of the dust deposit was increased to 6, 10 or 12 %, the explosion of the ignition source no longer propagated a dust explosion: see Fig. 1.

1.2.2. Montrambert coal (8.4 % inerts in dry state)

With dust only on the floor and a moisture content of 12 %, the flame proceeds at a speed which falls quickly once the effect of the ignition source ceases, between 35 and 60 metres. This may be seen in Figure 2 on comparing tests number 820 and 838 without moisture and test number 896 with 12 % moisture content. Here the explosion pressure 5 metres from the end was about 0.3 bars.

With dry dust deposited both on the floor and on boards, flame velocities are already higher than 100 m/s between 35 and 60 m (test 861, Figure 2) and the pressure is about 0.5 bar.

However, with a 12 % moisture content a very slight increase in the flame velocity beyond 35 metres (test 893) was observed and with a 15 % moisture content the flame velocity falls after 35 m (test 891). The 12 % moisture content is no doubt close to the maximum percentage giving a propagation probability of 50 % under our test conditions.

In this series of test, pressures were observed to be distinctly lower when the deposit was wet than when it was dry.

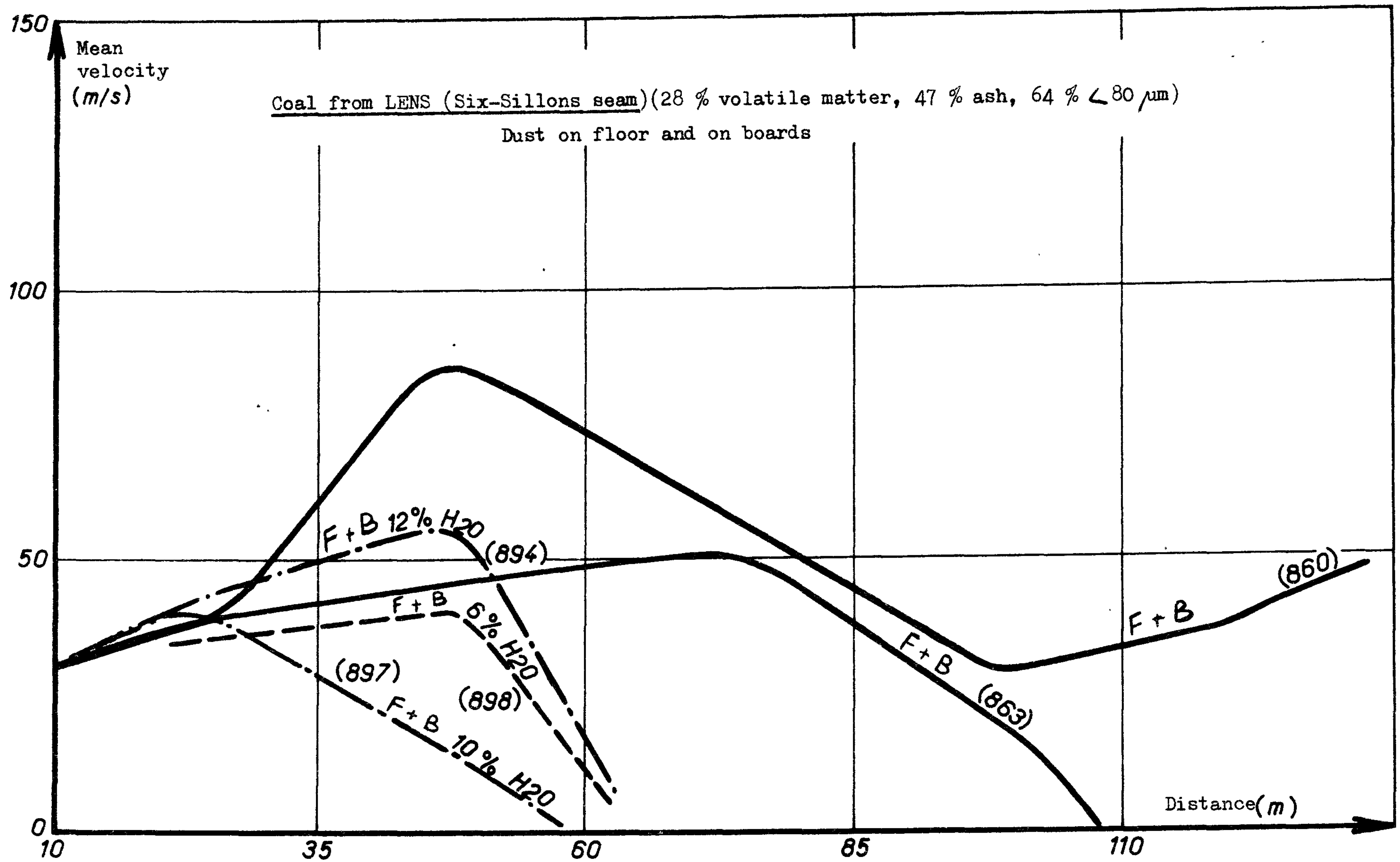


Fig. 1 - Mean velocity of the flame as a function of distance

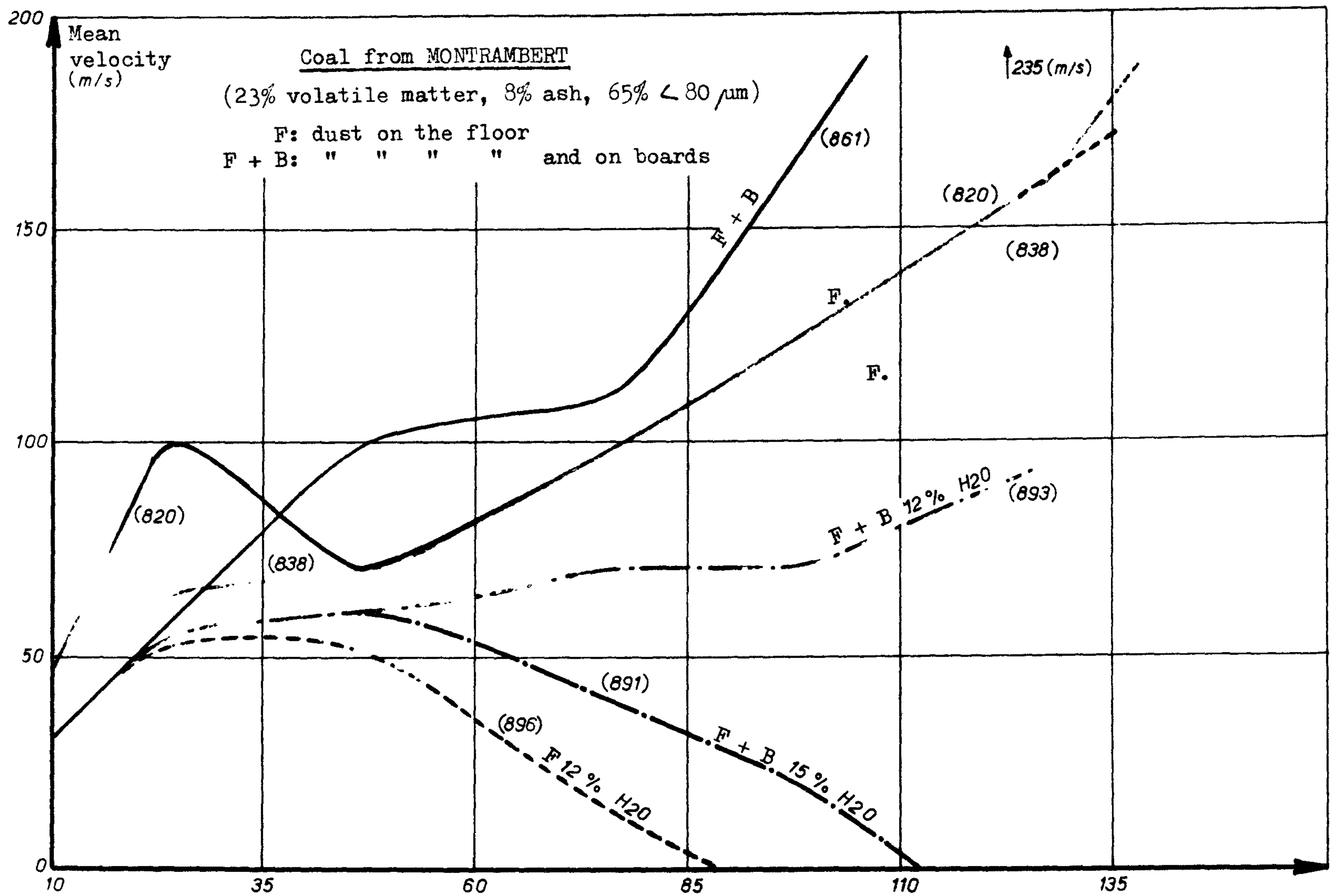


Fig. 2 - Mean velocity of the flame as a function of distance

With the same source of ignition but using calcareous dust rather than water to neutralize the Montrambert coaldust, we worked out the 'maximum neutralization ratio' for a 50 % probability of an explosion reaching the end of the gallery.

With dust on the floor only, the series of tests gave a maximum inert content of 46.1 %. However, this maximum content was found to be equal to 54 % when dust was deposited both on the floor and on boards.

A comparison of moisture or solid inerts necessary to bring down the risk explosion propagation in our Montlaville gallery therefore shows that a relatively small quantity of water - about 12 % - is required to prevent the dust transmitting an ignition, whereas a solid inert content of about 50 % is required to achieve the same results.

Water is therefore particularly effective when the source of ignition for the dust explosion is relatively weak.

2. Tests in a surface gallery with mixtures of coal, calcareous dust and water.

2.1. Test conditions.

2.1.1. Gallery.

The metal gallery, a diagram of which is given in Figure 3, is 1.8 m in diameter and 142.5 m long. The inner wall is smooth. A concrete floor brings the cross section down to 2.47 m^2 and forms a horizontal surface 0.8 m wide on which the dust is spread.

2.1.2. Source of ignition.

This was a firedamp pocket 10.5 m long and 28 m^2 in volume. The mixture containing approximately 9 % methane was ignited by firing 300 grams black powder in a mortar placed outside the gallery.

The flame from such a source of ignition generally spreads up to about 80 m from the end of the gallery. The average velocities of the flame produced were about 150 m/s between 0 and 18 m and fell to 60 m/s between 60 and 72 metres from the end. The degree of violence of this source of ignition may therefore be considered moderate. Pressure at 24 metres was about 1.9 bar.

2.1.3. Dust.

The dust deposits were prepared using coal from La Houve and Merlebach with the following average characteristics.

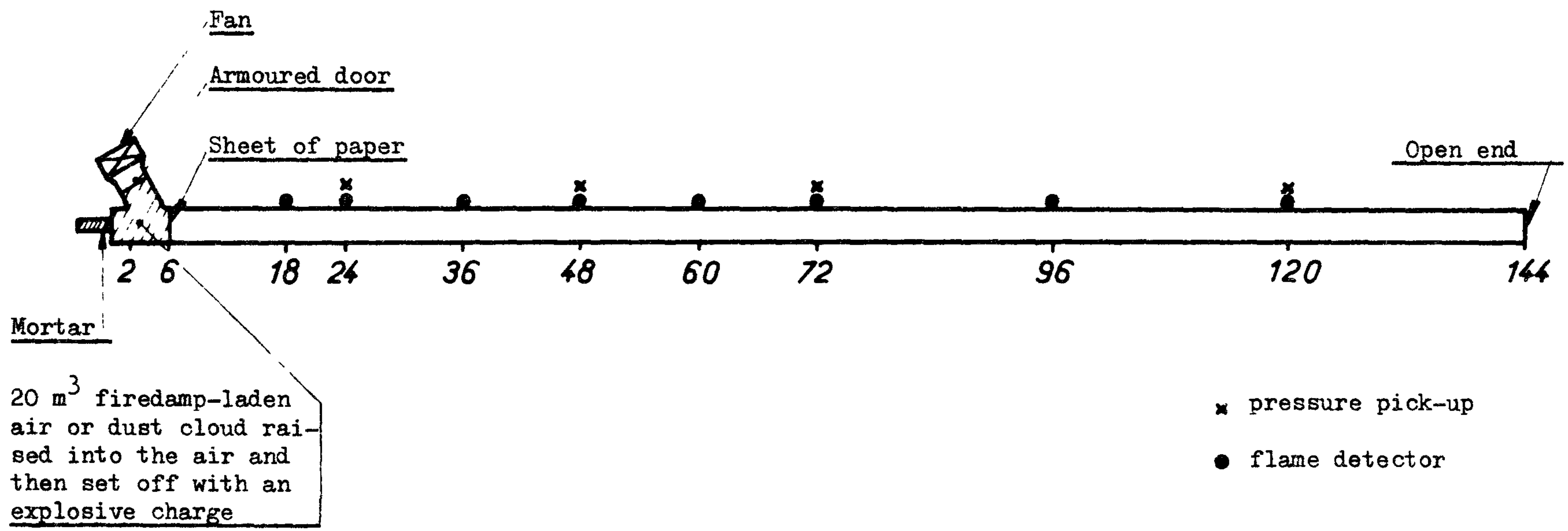


Fig. 3 - Large gallery

length = 144 m

cross-section = 2,5 m^2

Coal	Moisture content of the air-dried coal	Volatile matter index of the d.a.f.	Inert ratio of dry coal
La Houve	4.5	40.0	11.6
Merlebach	2.4	39.6	6.3

The dust was crushed for periods of time so that 75 % of it passed through a sieve with an 80 µm mesh.

As in the previous tests, the dust was wetted just before being deposited on the floor and a cement mixer was used to produce the mixes.

2.1.4. Evaluating the critical inert ratio.

Experiments were carried out using various percentages of water added to the coal and calcareous dust mixtures to find the critical inert ratios defined as the mean of:

- the highest figure for the inert ratio (ash + calcareous dust + adsorbed water) giving two explosions extending throughout the gallery;
- and the figure immediately above for the inert ratio, differing from the first by at least five points, which resulted in two failures to propagate an explosion.

This definition should allow the inert ratio corresponding to a propagation probability equal to 0.5 with an accuracy of about 2.5 %.

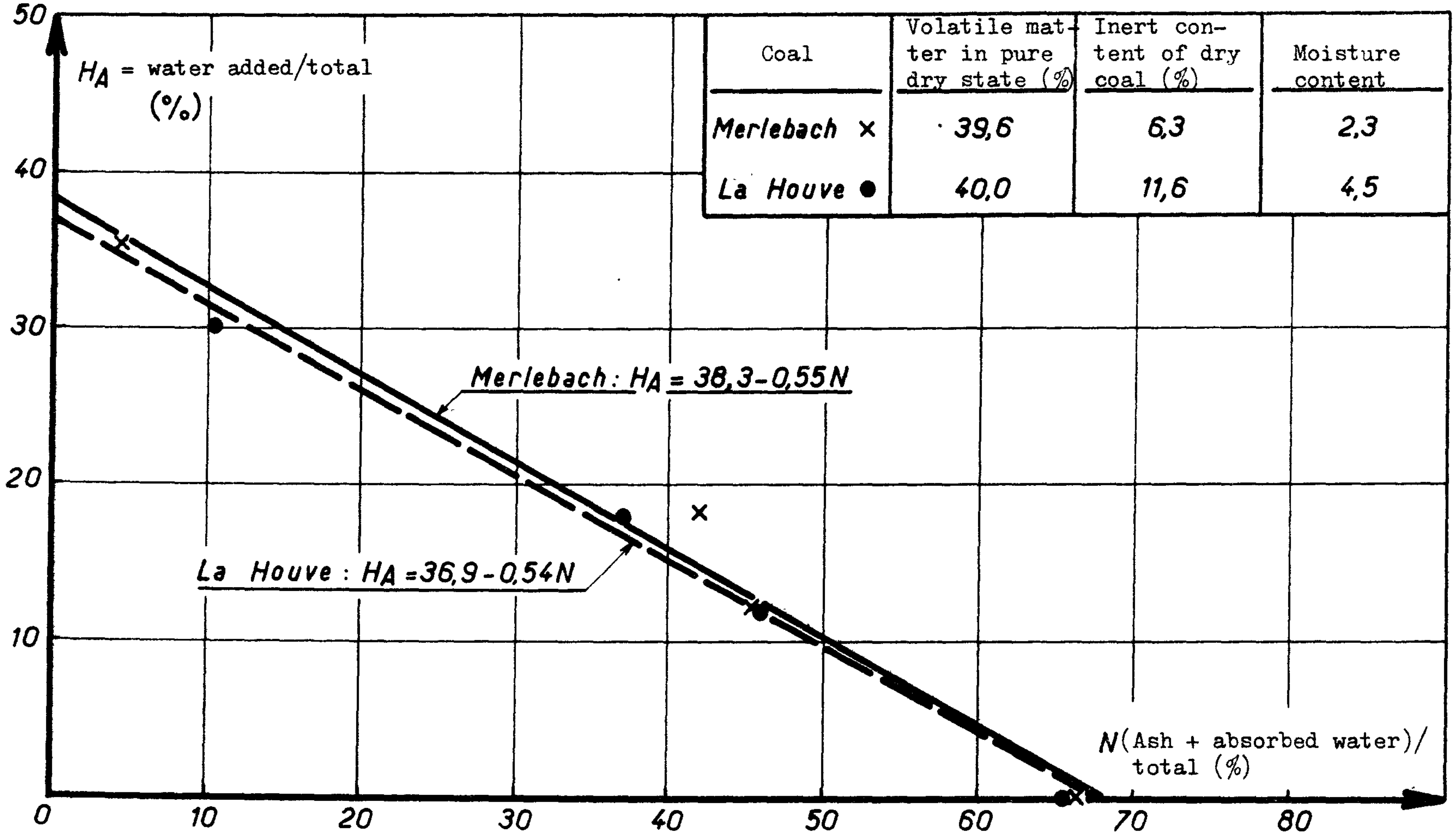
2.2. Results.

The tests carried out using Merlebach and La Houve coal gave the results in Figure 4.

The areas of propagation and non-propagation of the explosions are delimited by a straight line with a slope of approximately - 0.5.

As a first approximation, a decrease of 2 % in solid inert content may therefore be offset by an increase of 1 % in moisture content.

In the test conditions chosen, with a moderately violent source of ignition, an examination of the regression line plotted shows that with an ash content of zero, approximately 37 parts of water could be needed for 63 parts of coal (i.e. 0.58 parts water for 1 part of pure coal) to give a propagation probability of 50 %. Under the same conditions, the same result would be achieved with 68 % inerts and 32 % dry ash free coal, i.e. 2.1 parts inert for 1 part of d.a.f. coal. It may therefore be estimated that one litre of water is as effective as 2.1/0.58 ≠ ≠ 3.5 kg stonedust.



Coal	Volatile matter in pure dry state (%)	Inert content of dry coal (%)	Moisture content
Merlebach ×	39,6	6,3	2,3
La Houve ●	40,0	11,6	4,5

Fig. 4 - WATER ADDED/TOTAL AS A FUNCTION OF THE (ASH + ABSORBED WATER)/TOTAL CONTENT

Coal from La Houve and Merlebach - Primer: 28 cubic metres of air containing 10% methane and 300 grams of black powder in a mortar

This is all more significant as water is always available near workings and may be used at all times to wash the walls or wet dust on the floor whereas stonedusting cannot be undertaken without evacuating the staff downwind of the area to be treated.

Nevertheless, it should not be forgother that these results were obtained with perfectly mixed mixtures of coal, calcareous dust and water.

B - EFFECTIVENESS OF WIDE-ACTION WATER BARRIERS INSTALLED NEAR THE IGNITION POINT OF A DUST EXPLOSION

For a water safety-barrier to be effective it is known that the rush of air preceding the flame must break up the troughs and produce a sufficiently big cloud of water droplets.

In view of the fact that water troughs often cannot be set up in roadway sections overcrowded by equipment and staff working in them, the best use possible should be made of those located near such critical zones to provide effective prevention against any explosion occurring there. Unfortunately, it is not always possible in practice to install troughs under the conditions which are theoretically the best.

Some findings of tests carried out with a moderately violent source of explosion are given here. These tests made it possible to evaluate the relative importance of recommendations regarding the installation of water troughs and especially those of wide-action barriers.

1. Test conditions.

1.1. Gallery.

The tests were carried out in our Montlaville gallery briefly described above.

1.2. Source of ignition.

We initiated the explosions with the ignition source described in paragraph A 1.1.2. (firing of an explosive charge to set off a cloud of raised dust).

1.3. Dust deposit.

Most of the tests were carried out with Montrambert coal dust deposited solely on the floor. Nevertheless, for some tests the dust was partly placed on 11 balanced boards and partly on the roadway floor.

1.4. Location of the wide-action barrier.

The wide-action barrier was made up of four rows of 80-litre troughs placed 20 metres apart and located 35, 55, 75 and 95 metres from the end of the gallery so that the water concentration calculated with respect to the gallery volume was approximately 0.5 or 1 litre per cubic metre depending on whether there were one or two troughs per row.

The troughs used were made either of PVC or of expanded polystyrene. Their broad sides were placed across the roadway or along it. Figure 5 shows some of the ways in which troughs were placed for the tests.

2. Findings from tests.

Test findings have been grouped together in table form.

Table I shows that for moderately violent explosions, there is no great difference between the effectiveness of troughs placed on and those inserbed into supports, nor between troughs in PVC or in expanded polystyrene. Furthermore, expanded polystyrene troughs the bottoms of which were held in a framework fixed firmly to the walls gave results which were as good as those for troughs slipped into supports and held by their rims.

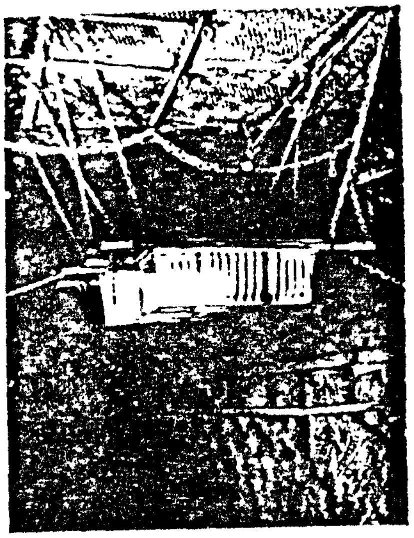
Table II highlights the importance of fixing troughs: when they are hung from vertical chains and may swing their effectiveness is lower. This aspect was confirmed by tests under similar conditions to those in Table I but in which the trough supports were not fixed rigidly to the walls.

The tests given in Table III show that it is important to leave a free space above the covers. Part of the water must be expelled for the trough to break and for its contents to be spread properly.

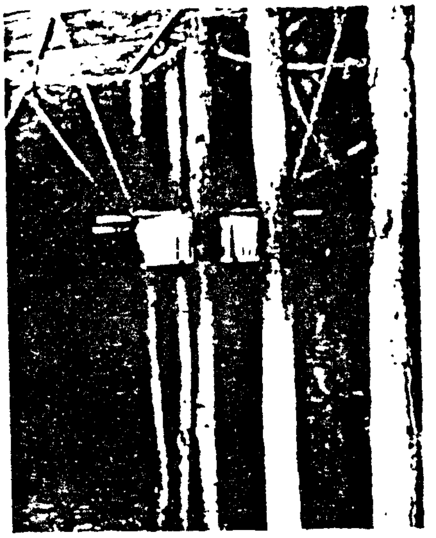
Troughs may need to be moved further towards one wall of the roadway to leave room for a passage or they may need to be placed on the floor, either to safeguard the space under a belt-conveyor or because a barrier must be set up very quickly - to protect rescue teams for example.

The tests in Table IV were carried out with troughs placed lengthwise across the roadway. The results showed that a trough which is set nearer one wall may protect a width of roadway of the order of three metres when it is unrestricted and installed under good conditions (i.e. with broad side across the roadway axis and fixed firmly). Even troughs placed lengthwise across the roadway axis at floor level are effective to some extent.

Table V gives the tests conducted in a roadway with a row of props one to two metres apart. It may be observed that troughs set up in one of the tracks formed by the props may be fairly effective and it is much better to set them up this way than between two props. It should be pointed out that during these tests some difference between troughs inserted into and those placed on supports was observed. Placing troughs on the supporting



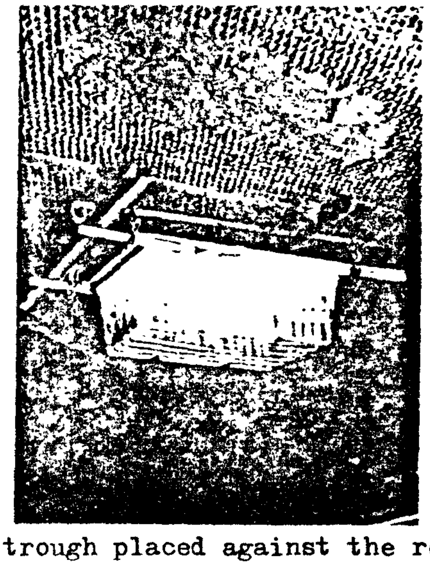
group of troughs placed lengthwise across the roadway



trough between props

group of troughs placed lengthwise along the roadway

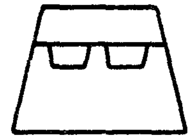
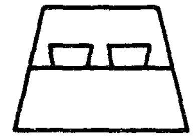
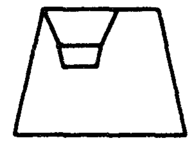
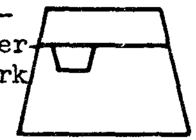
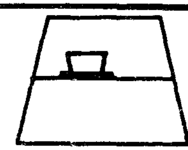
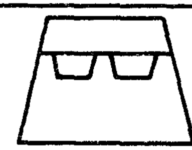
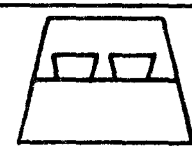
trough placed lengthwise along the roadway axis



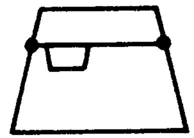
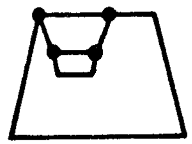
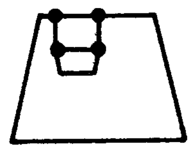
trough placed against the roof

trough hanging from vertical chains

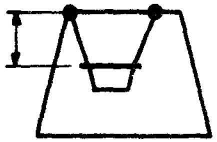
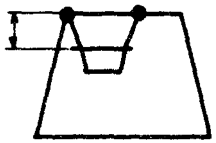
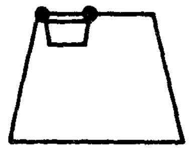
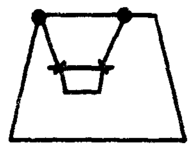
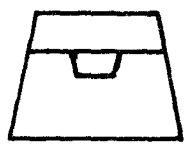
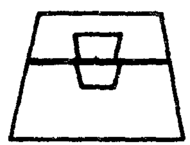
Fig. 5 - TESTS ON WATER TROUGHS

Dust deposit	Position of troughs			Litres of water per cubic metre ℓ/m^3	Number of tests	Distance in metres covered by flame (m)	
						Highest and lowest values	Average
Floor	Lengthwise across the gallery	troughs inserted into supports		1	5	60-65	64
		troughs placed on supports		1	2	60-75	67
		troughs inserted into supports		0,5	3	65-95	80
		Expanded polystyrene troughs inserted into framework and held by rims		0,5	2	95-110	103
		EPS troughs with bottoms inserted into framework		0,5	2	95	95
Floor + boards		troughs inserted into framework		1	4	60-75	63
		troughs placed on framework		1	4	60-90	77

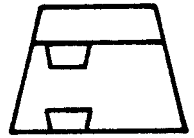
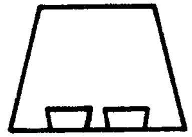
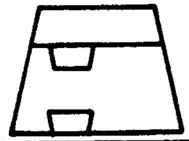
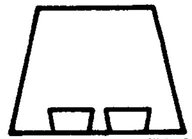
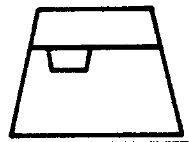
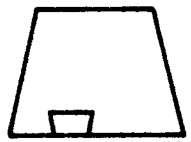
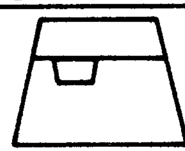
- Table I -

	Position of troughs		Number of tests	Distance in metres covered by flame (m)	
				highest and lowest values	average
– Troughs placed at right angles to the gallery – troughs inserted into framework – dust deposit on floor – litres of water per cubic metre: 0.5	Frameworks fixed solidly to walls		4	65 - 110	87
	framework + chains taut chains set at a slant		3	65 - 95	80
	framework + vertically hung chains		1	110	110

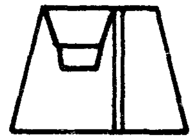
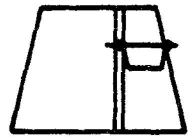
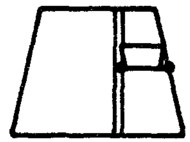
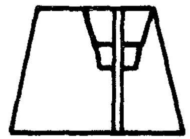
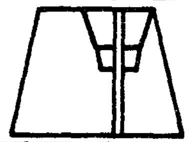
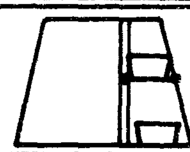
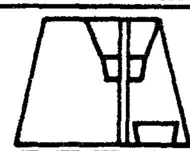
- Table II -

	Position of troughs	litres of water per cubic metre (ℓ/m^3)	number of tests	Distance in metres covered by the flame (m)	
				highest and lowest values	average
— Troughs placed at right angles to the gallery — Troughs inserted into the supporting framework — Dust deposit on the floor	0,7 to 1,2 m 	0,5	3	65 - 95	80
	0,4 m 	0,5	3	75 - 95	85
	covers against the roof 	0,5	2	110 - > 145	> 127
		1	1		130
	0,7 to 1,2 m Wooden covers bolted to supporting framework 	0,5	1		115
		0,5	2	65 - 82	73
	Two troughs one above the other 	1	1		67

- Table III -

Dust deposit	Position of troughs		Litres of water per cubic metre ℓ / m^3	Number of tests	Distance in metres covered by flame (m)	
					Highest and lowest values	Average
Floor	Lengthwise across the gallery		1	2	65	65
			1	1	65	
Floor + boards			1	1	65	
			1	1	65	
Floor			0,5	4	65-110	87
			0,5	2	97-110	103
Floor + boards			0,5	1	> 145	

– Table IV –

	Position of troughs	Litres of water per cubic metre ℓ/m^3	Number of tests	Distance in metres covered by flame (m)	
				Highest and lowest values	Average
- Troughs placed at right angles to the gallery - Dust deposit on the floor		0,5	3	65	65
	Troughs inserted into supporting framework 	0,5	2	67-82	75
	Troughs placed on supporting framework 	0,5	2	130->145	>137
	1 trough every 20 m 	0,5	4	75->145	>110
	1 trough every 10 m 	1	1	97	
		1	1	97	
		1	1	97	

- Table V -

framework produces appreciably less satisfactory results than slipping them into it when the troughs are in the narrowest track.

The tests in Table VI highlight the importance of properly separating troughs set one behind the other and of placing them lengthwise across the roadway axis. If the effects of poor installation conditions, such as placing troughs both lengthwise along the roadway axis and very close to each other, are combined, simply increasing the quantity of water does not lead to any greater effectiveness of the barrier.

As a result of these tests on wide-action water barriers carried out with moderately violent explosions (flame velocity of the order of 60 to 90 m/s in the barrier area) the following recommendations for achieving maximum effectiveness in order of increasing importance may be given:

- troughs which are inserted into supports are slightly more effective than troughs which are simply placed on the supports;

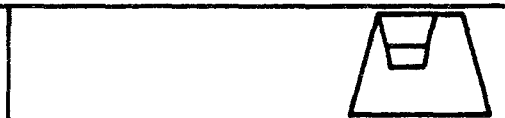
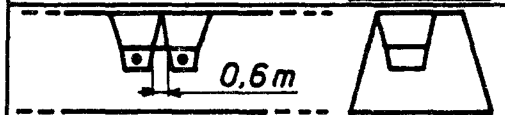
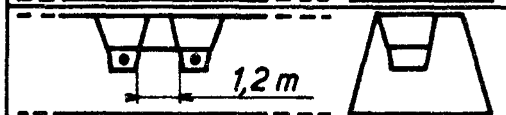
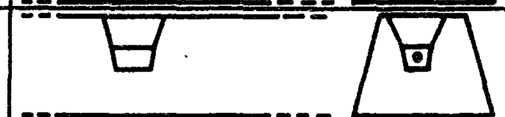
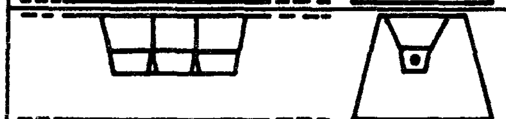
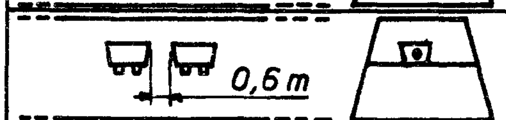
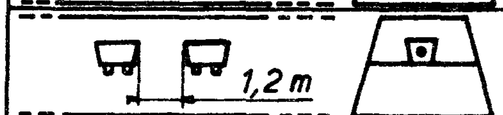
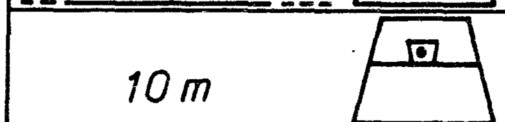
- troughs placed one behind an other in a line parallel with the roadway axis should be at least 1.2 m apart;

- troughs should not be placed behind props;

- troughs should not be placed against the roadway roof - at least if it is more than 2-3 metres high - and they should not be placed on other troughs;

- trough frameworks or supports should be of such a design that troughs cannot be rocked or displaced before being broken up;

- troughs must have their broad sides at right angles to the roadway axis.

Dust deposit	Position of troughs		Litres of water per cubic metre ℓ/m^3	Number of tests	Distance in metres covered by flame (m)	
					Highest and lowest values	Average
Floor	Lengthwise across the gallery		0,5	3	65-95	80
			1	2	67-97	82
			1	2	65	65
	Lengthwise along the gallery axis		0,5	2	140	140
			1	1	110	
			1,5	1	>145	
			1	2	132-140	136
			1	2	105-115	110
			1	2	97-105	101

- Table VI -

Mr Schnier

New operational developments in the use of dust-binding in the Federal Republic of Germany

1. Introduction

In the West German coal mining industry hygroscopic salts are used to consolidate potentially explosive coal dust. These salts (calcium chloride and magnesium chloride are in common use) may be applied in the form of paste, powder, flakes or as an aqueous solution to the floors and other surfaces of roadways. In view of the importance of this technique, the Mines Safety and Health Commission, acting on a proposal from the Working Party on Flammable Dusts, issued a recommendation on dust-binding by hygroscopic salts in 1976 (Doc. 735/76).

As the techniques which were then available for dust-binding operations have since been further developed, some details may be of interest. Like other methods of protection against explosions (e.g. stone dusting) dust-binding requires a certain amount of labour, may impede the conduct of operations and involves the use of haulage media. The purpose of further development was and is to reduce the effect of these factors.

2. Application of salt paste

Shortly after the introduction of dust-binding agents in paste form, an attempt was made to improve efficiency by providing central pumping stations. Initially, only individual panels or a single working level were centrally supplied, the paste being delivered in converted mine cars or in trucks with a pressure tank.

The present trend is towards supplying an entire colliery from the surface via shaft and roadway pipe ranges (Figure 1). Eight collieries in the West German coal mining industry are currently equipped with central supply installations and others are preparing to introduce such systems.

The surface supply stations consist of a number of silos and pumps for delivery of the material to the shafts. They are installed at shafts which are suitably located in relation to the working area below ground (Figure 2).

The paste is delivered to the working levels through high-pressure pipe ranges between 40 and 80 mm in diameter. 25 mm pipes are generally installed in level roadways. As a result of the static pressure developed in the shaft range, it is possible to supply delivery points at distances of up to 1500 m without the use of pumps. For more distant workings, automatically controlled high-pressure pumps with a working pressure of 300 bars are used. With such systems it has so far been possible to supply paste over a distance of up to 5.5 km (Figure 3).

Capital costs for a medium-sized colliery amount to DM 500 000 to 700 000. They may, however, be recovered in as little as 2 years through savings of labour and material.

Such measures make it possible to dispense with the labour required for mine car and container transport and for pump operation. This amounts to a saving of at least 5 shifts per day while simultaneously improving performance.

The paste compositions are currently standardized at a salt concentration of 28 % for calcium chloride and
20% for magnesium chloride.

As the depth of working and consequently the mine temperatures increase, there may be a drop in relative humidity. In such cases the standard paste may dry out before it is exhausted. It is then desirable to increase the salt content to the point of saturation, i.e. not more than 33%, at which concentration it is in equilibrium when the relative humidity is 55%. While this makes the paste somewhat more expensive, increases of up to 80% have been achieved in its service life.

3. Application of calcium chloride powder

When powder is used, the method normally employed is still to lay out bags of 30 kg capacity in the roadways to be treated. The powder is aspirated from the bag with a compressed-air-operated ejector and blown over the roadway periphery by means of a discharge hose. For a long time, no further development of the technique took place, with the result that it seemed likely to decline in importance because of the fairly high labour requirements as compared with the use of paste and because of the nuisance to which it gave rise.

It has recently become possible to deliver $CaCl_2$ powder in large packs of 800 kg and over (Figure 4). The salt powder is loaded directly from these packs into large containers specially designed for transport below ground (Figure 5). These containers are transported by means of floor-mounted rail systems or overhead monorails to the point of application, where the powder is aspirated through apertures in the sides of the containers and blown over the surfaces to be treated. Such containers are currently produced by the firm Müller & Borggräfe. They cost DM 5 000 to 6 000.

In order to improve the discharge rates, one colliery converted existing Rheinelbe pressure vessels which were previously used to deliver dry stone dust or materials for pack construction (Figure 6).

There is certainly scope for further development of the technique by improved methods of transport to the point of use.

The new containers have permitted an increase in performance, ranging from 30 to 70% according to circumstances of use, together with saving in labour costs.

As in the past, a disadvantage of the use of powder remains the dust nuisance, which is undesirable, although not a hazard for the workers. Powder spreading is therefore usually carried out during the shift when least other work is in progress, i.e. often at the weekend.

In some collieries, a calcium chloride powder dispenser, as illustrated in Figure 7, is used for dust control at belt conveyor transfer points. The device consists of a small container filled with calcium chloride powder, which is suspended at the transfer point. The discharge port at the bottom of the device is filled with a cover held in place by elastic. The cover is caused to vibrate by compressed air and continually allows small quantities of powder to escape. The powder mixes with the coal dust dispersed at the transfer point and is also deposited on the conveyed mineral.

4. Application of calcium chloride solution

As a remedy for the above disadvantages of powder spreading, it was necessary to have recourse to a technique previously employed, viz the production of salt solutions. A 30% calcium chloride solution was mixed in containers or delivered ready-mixed. The salt solution was pumped into a supply line consisting of 25 mm pipes or 19 mm hoses. At the places of application, the solution is sprayed on the roadway periphery with the aid of a spray pipe (Figure 8). A spraying car was developed for use in fairly long roadways with rail track (Figure 9).

A low-pressure reciprocating pump forces the calcium chloride solution, which is produced in the car, through discharge nozzles which are arranged in a circular configuration with individual feed. It is thus possible to work selectively and to avoid spraying roadway installations which are liable to suffer damage.

This technique permits high levels of performance, though the spraying process must be repeated more frequently than is the case for the other dust-binding techniques. No reliable indication can as yet be given of its cost-effectiveness.

5. Treatment with calcium chloride flakes

Calcium chloride flakes are particularly suitable for dust consolidation on the roadway floor. Salting cars similar to those used for road salting have been developed and used for this purpose. As yet the method still suffers from the disadvantage that the distributing plate which serves to discharge the salt is placed fairly high with the result that the flakes do not reach the floor below the bottom strands of low belt conveyors. Here, too, further development will lead to improvements (Figure 10).

6. Conclusion

New operational developments in the use of dust-binding offer the following advantages:

- better, sometimes constant, availability;
- increased performance and reduced labour requirements;
- lowering of operating costs;
- less interference with mining operations as a result of the provision of separate transport systems (e.g. pipe ranges).

Improved availability is of particular importance for purposes of protection against explosions.

Illustrations for the paper

"New operational developments in the use of dust-binding in the Federal Republic of Germany"

Figure 1: Layout of a central paste supply system

Figure 2: Paste supply installation above ground

Figure 3: Automated central pumping station below ground

Figure 4: Large-capacity pack for calcium chloride powder

Figure 5: Large-capacity container for the use of calcium chloride powder below ground

Figure 6: Use of a Rheinelbe pressure vessel for calcium chloride powder

Figure 7: Vibratory dispenser for calcium chloride powder

Figure 8: Spray pipe for salt solution

Figure 9: "Minister Achenbach" spraying car

Figure 10: Floor-salting car

Abbildungen zum Referat

"Neue betriebliche Entwicklungen bei der Anwendung der Staubbindeverfahren in der Bundesrepublik Deutschland" (M. Schnier)

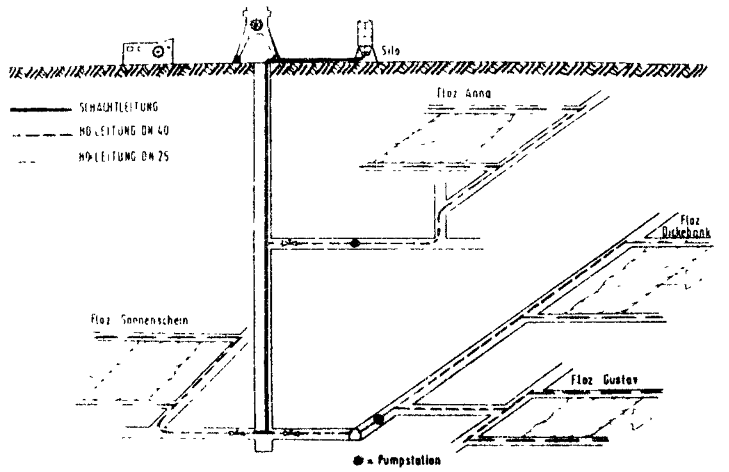


Bild 1: Layout of a central paste supply system
Schéma d'un système d'approvisionnement central en pâtes
Schema einer zentralen Pastenversorgung

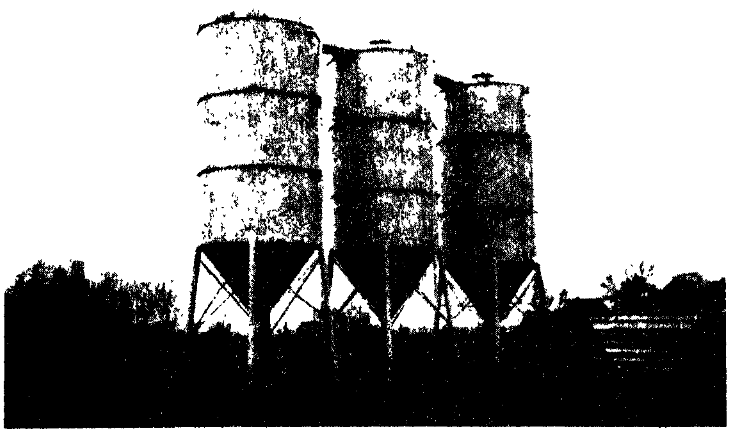


Bild 2: Paste supply installation above ground
Installation d'approvisionnement en pâtes au jour
Pastenversorgungsanlage über Tage

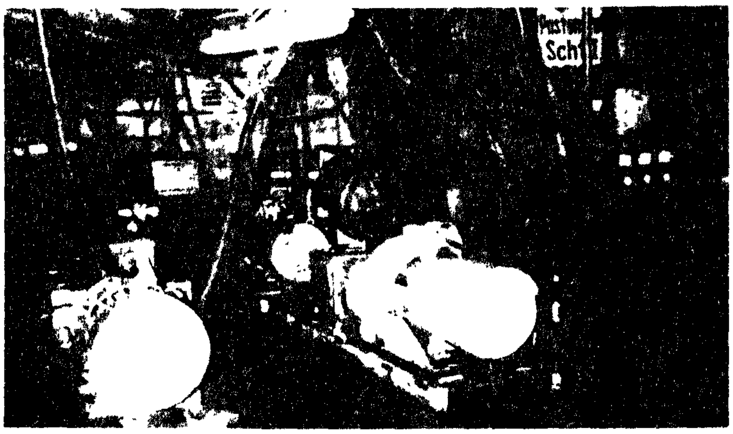


Bild 3: Automated central pumping station below ground
Station centrale automatisée de pompage au fond
Automatisierte Zentralpumpstation unter Tage

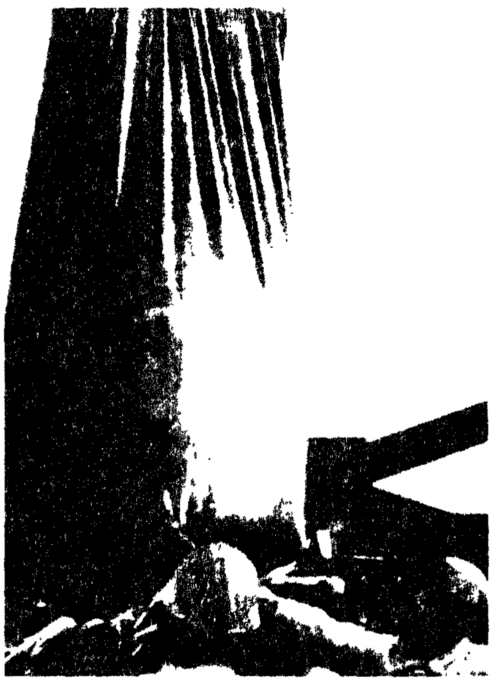


Bild 4: Large capacity pack for calcium chloride powder
Récipient de grande capacité pour le transport de la poudre de chlorure de calcium
Großgebinde für Calciumchlorid-Pulver

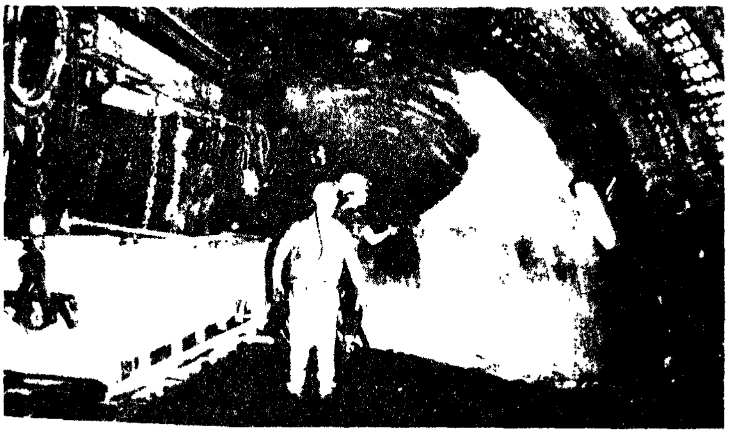


Bild 5: Large-capacity container for the use of calcium chloride powder below ground

Conteneur de grande capacité pour l' utilisation au fond de la poudre de chlorure de calcium

Großbehälter für die Untertageverwendung von Calcium-chlorid-Pulver

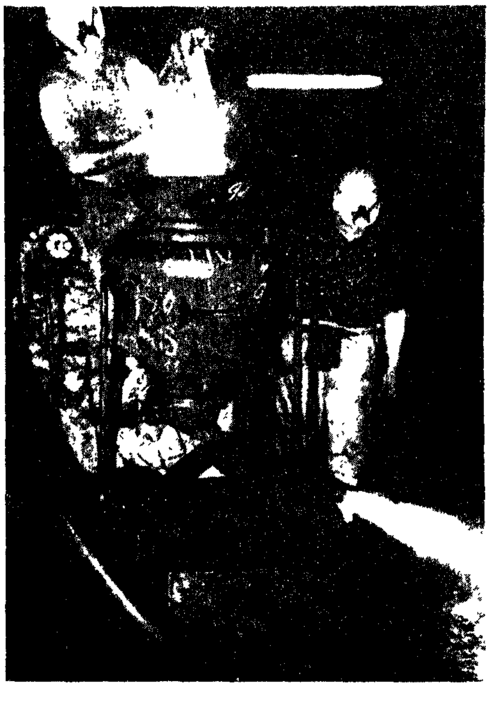


Bild 6: Use of a Rheinelbe pressure vessel for calcium cloride powder

Utilisation d'un appareil à injection "Rheinelbe" pour l'épandage pneumatique de la poudre de chlorure de calcium

Verwendung eines Rheinelbe-Kessels für Calciumchlorid-Pulver

Bild 7: Vibratory dispenser for calcium chloride powder
Appareil vibrateur pour la poudre de chlorure de calcium
Vibrationsgerät für Calciumchlorid-Pulver

Bild 8: Spray pipe for salt solution
Canne pour la dispersion de la solution saline
Düsenstab für Salzlösung

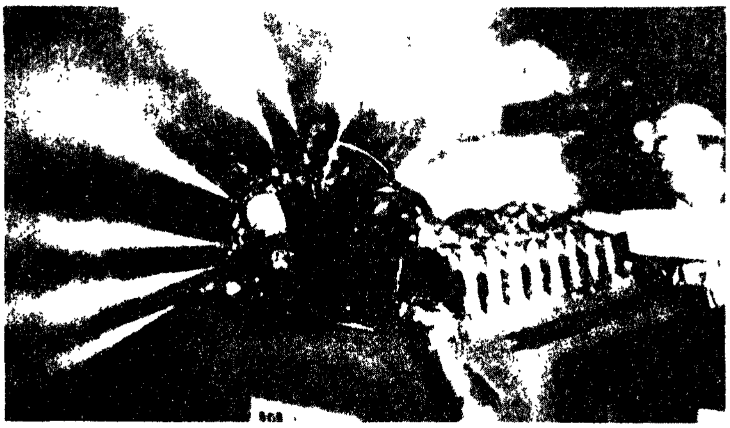


Bild 9: "Minister Achenbach" spraying car
Wagon du type "Minister Achenbach" pour pulvérisations
Sprühwagen System "Minister Achenbach

Bild 10: Floor-salting car
Wagon épandeur pour la sole
Sohlen-Streuwagen

FUTURE OBJECTIVES IN ARRESTING EXPLOSIONS Ainsworth

During recent years methods of extraction have witnessed radical changes as the burden of high capital cost of equipment and other economic factors have increased rapidly in a period of high inflation demanding an increased return on investment. The effects of these influences has resulted in production being obtained from fewer faces, with a marked increase in HP to achieve higher levels of output. Changes in machine performance and improvements in support design have encouraged full seam extraction.

Unfortunately there is a resultant tendency of ignitions due to frictional sparking caused by rotating picks making contact with quartzic material in either the roof or the floor.

On average 17 ignitions occur each year in UK mines fortunately all of a minor nature and of this number an average of 15 are due to frictional sparking during the operation of cutting or power loading machines. The reduced severity of the ignitions can be attributed to a combination of good ventilation, the generally adopted practice of methane drainage, making cutting machines more responsive to horizon control by fitting sensing devices and the adoption of hollow shaft ventilation to dilute methane in the cutting area.

As powered supports dictate the cross sectional appearance of a face it should be appreciated that fundamental changes in the design of supports may have a profound bearing on potential ignitions. For example shield supports which are being introduced in increasing numbers produce a profile of tube-like proportions. The migration of methane from the goaf on faces equipped with shield supports and the effect of any restriction for example in the machine area and its influence on an ignition are matters calling for closer examination. Protection against explosions may eventually be considered necessary on longwall faces as well as in roadways. As containment of an ignition to prevent spread is of primary importance, means of extinguishing may require to be in close proximity to the point of origin. Thus on faces equipped with shield supports and perhaps other types of powered supports release of water or other non-hazardous extinguishing material carried on the supports or indeed on machines could provide a distributive quenching arrangement on the detection of a sudden temperature rise. The rate of release of the quenching material in the confined profile of a longwall face should be such that injury to workmen in the vicinity would not occur.

Barrier protection in UK mines is confined to roadways where coal is conveyed and in most mines this generally means Intake roadways. During recent years ignitions have tended to take place between the mid point and return end of longwall faces. The implications of this trend are given further emphasis by the deposition of coal dust in return airways as a consequence of higher rates of extraction and larger quantities of air traversing faces at increased velocities, which can to some degree be counteracted by the adoption of effective dust suppression measures and systematic cleaning up and stone dusting. The time may be approaching when a departure should be made from existing practice which was after all devised when machine cut hand filling was customary and consider the adoption of barrier protection in all roadways leading to a production unit. Thus providing a means of isolation from other production areas.

Barrier protection consists of whole or part width stone dust barriers now being augmented by Triggered Barriers as an alternative to stone dust barriers sited near to the anticipated ignition. Water trough barriers have been used in a few isolated cases but have not found favour for requirements. Experience with Triggered Barriers has shown that handling problems can arise in certain conditions, which would seem to suggest that a move towards smaller disperser units for manoeuvrability in roadways under 2m in height might be given consideration.

The positioning of stone dust barriers sited near to the anticipated ignition is most important, but with the rapid rates of advance now being achieved on advancing and retreating faces, frequency of movement of barriers becomes important; the less frequently the better. It is essential that production is not hindered whilst at the same time a barrier protection is provided continuously. A distributive barrier system achieves both these objectives. The selection of any barrier system should therefore be determined with these aspects in mind.

The emphasis on barrier protection has been up to the present time towards protection against coal dust explosions. In view of the frequency of methane ignitions the detection of sudden temperature and other variations in the very early stages of development is most important in initiating protective measures. The existance of miniaturised electronic equipment may have a contribution to make in this direction.

In view of the constantly changing methods of mining techniques it is becoming increasingly difficult to carry out research under simulated conditions. In order to provide management with a catalogue of possible projections and variations greater emphasis may have to be given to the acceptance of computer analysis.

Whilst due recognition has been given to Cybulski's approach to barrier protection in conventional mining operations, it has been appreciated in the UK that because of sophisticated changes in mining environments a sophisticated approach must be adopted in dealing with potential explosions. It is hoped that the contents of this paper indicate the direction on which progress needs to be made.

A.J.L. Ainsworth.

18 March 1981

SYMPOSIUM ON EXPLOSIONS AND TRIGGERED BARRIERS

LUXEMBOURG, 5TH NOVEMBER 1981

Operational Experience with Triggered Barriers within the U.K.

by J. L. Collinson and R. T. Pye

INTRODUCTION

In addition to the basic method of general stone dusting to arrest underground explosions practised for a long time, U.K. mines have for more than 25 years used types of stone dust barriers on coal conveyor roads associated with the coal face. These have been light, intermediate and heavy type stonedust barriers. Early in the 1970's there was an increase in retreat mining in in-seam conditions necessitating lower and square roadways and it was found that the many shelves of a light stone dust barrier were not easy to maintain or advance. In view of this changed mining technology research and development was initiated to design a replacement for the light stone dust barrier and eventually the flame triggered water barrier was conceived, developed and tested.

During the development stage operational trials were carried out underground with the equipment in an unarmed condition basically to assess handleability and thereafter armed trials were conducted. Its safety if water discharge occurred on to a man was tested in animal trials.

During the development, gallery trials had been conducted and this produced some limitations in that tests could only be carried out in galleries up to $7m^2$ and with distances between the dispersers and the side of the roadway of up to 2m. Subsequently approvals were granted by the U.K. Mining Inspectorate to proceed operationally with triggered water barriers as acceptable alternatives to light stone dust barriers in U.K. coal mines.

By early 1981 two installations had been in full operation in the U.K. This paper describes operational experience so far and includes elements of training, handling, fault experience and maintenance.

PRE INSTALLATION

Experience has shown the necessity to conduct comprehensive training of individuals both officials, workmen and craftsmen who would be involved with the triggered barriers and it has also shown that the actual suspension and handling of the triggered barriers during transport and on site had to be given considerable attention in addition to just the design of the barrier itself.

For training before the installation took place, personnel were selected and the training conducted at a Board workshop. This introduced all personnel to the new system, enabled those who had to handle the equipment to have practice in so doing, enabled craftsmen to be acquainted with the regular routine maintenance that would be required by them and enabled officials on whose districts barriers would be installed to be familiar with the whole working of them and the daily examinations which they themselves would have to conduct. Each man involved had a one day's training.

Prior to installation underground the barriers were erected in a simulated roadway and various experiments carried out to determine the best way of handling and advancing these units.

INSTALLED EXPERIENCE

Careful attention was given to the selection of sites for initial operational experience and the first triggered barrier was installed at Royston Drift Mine on a rapidly retreating longwall face in a rectangular roadway of dimensions some 3.7m wide by 2.1m high. It was anticipated that due to the short design life of the face (some 4 months) early experience would be gained both in installation, movement and (importantly) withdrawal and transport and re-installation. The installation necessitated, because of the roadway size, 4 disperser units and 2 flame sensors and these were disposed 2 over the travelling track and 2 over the gate conveyor. Their positioning was such that the first sensor was 30/50m from the coal face and the most outbye disperser some 90/110m from the face.

Suspension was by mono rail in each case and movement of the barrier was conducted twice weekly. Experience has shown that this was done in these early stages with 2 men taking time rather more than was expected with the equipment then being used and subsequent experience has enabled better handling arrangements to be designed and the next installation is proving easier to handle.

The first adverse operational experience was the unexpected spurious operation of a disperser after only four weeks of installation. This was proved to be a technical problem with the thermocouple wires in the detector head and a subsequently improved design has been evolved and there has been no further problem in this regard.

Naturally a very close watch had to be kept for maintenance of nitrogen pressure (7 bar) and ensuring that no leakage of water was apparent. In this early operational experience neither of these possible failures manifested themselves.

The spurious operation raised the problem of replacement and in order to continue to work the face legally with one barrier unoperational the colliery reverted to a light stone dust barrier installation. This experience highlighted the necessity for a spare unit not only to be readily available but easily transported to the site. Subsequently it has been recognised by the Inspectorate that in such an event production can continue provided that a replacement is erected with all possible speed.

This first site at Royston has been succeeded by two further retreating faces at the same colliery and no further adverse experience has been gained. Face lengths have been about 90 metres and the faces have retreated at up to 50 metres per week.

The earlier operational experience of handling difficulties has enabled refined designs of support and movement equipment to be developed and this is proving far more successful than the earlier type.

The second substantial operational experience was gained at Easington Colliery on a retreating longwall district in a roadway of similar dimensions to Royston. Handling has been improved as a result of the Royston experience and facilities are now one monorail and one running clamp on the permanent supports.

No repetition of the spurious operation at Royston was encountered but at Easington as opposed to Royston a minor leak of nitrogen was detected after 2 weeks. This eventuality had been foreseen and the barrier was able to stay operational by topping up with nitrogen from a nitrogen cylinder through the specially prepared Shrader valve. The cause of the leak has already been diagnosed as a badly designed seal and obviously other installations are having this design fault corrected.

In both of these installations the designed maintenance schedules appear to have worked well and a copy of these is attached.

CONCLUSIONS

Whilst fortunately the triggered barrier has not had to be used in explosion circumstances it seems apparent at this early stage that it is reliable and able to do its job, that it is relatively easily advanced in these especially difficult circumstances and that the maintenance standards are working well. It is certainly clear that there must be the necessary training.

It is believed that further operational experience will enable still further improvements in both transport and face handleability to be designed and it seems that the triggered water barrier is a useful alternative to the light stone dust barrier in specific conditions in the U.K. Indeed, it is well known that stone dust barriers are difficult to maintain with exactly the right quantities of suppressant but at least the triggered barrier as a designed piece of equipment is certain to be of the required standard at any time if properly maintained. Currently it is intended to instal the triggered barrier in 9 other collieries in the U.K. to gain further operational experience.

It is recognised as unfortunate that because of the limited dimensions of the gallery during the development period that 4 dispersers have to be used in this sort of roadway. There is the possibility that an equally effective explosion suppression could be gained by using 2 dispersers instead of 4 and this would considerably ease operational problems with no lessening of safety standards.

April 1981

MAINTENANCE

NCB COLLIERY INSTALLATIONS

In addition to carefully prescribed siting it is obvious that the Triggered Barriers' continued effectiveness will depend on proper maintenance. This should be included in the Manager's scheme for the mine.

Maintenance falls into three classes depending on the expertise required:-

(a) Operational Mining surveillance;

(b) Mechanical Engineering maintenance;

(c) Electrical Engineering maintenance.

Three separate disciplines are involved and the recommended frequency of the maintenance inspections depends on the depth of maintenance being conducted.

It seems quite clear that the Mechanical and Electrical maintenance will be carried out by the Engineering staff of the mine. The Operational maintenance is a relatively superficial examination and does not require engineering staff to carry it out (unless defects are found). In view of the importance of ensuring the barriers are continuously in readiness it is suggested that these Operational examinations be carried out by Deputies on each of their pre-shift examinations in common with other district safety checks.

[illegible]

The maintenance [illegible]

1. Examination 'A' [illegible]

2. Examination 'B' [illegible]

EXAMINATION 'A'

Examination

1. Check that the [illegible] as indicated by the gauge [illegible] range 90 – [illegible] p.s.i.

2. Remove water [illegible] the unit at the [illegible] and check that the [illegible] within [illegible] filling hole. [illegible] the water surface [illegible] [illegible]

3. Replace filler [illegible]

4. Insert [illegible] (engraved TBM) in sensor unit. Turn two positions clockwise to "TEST" position. The adjoining Light Emitting Diodes (L.E.D.) should light momentarily (One for each disperser in circuit and one to indicate satisfactory battery condition. Any decrease in brilliance of battery L.E.D. is an indication of low battery condition). Return master key to "ON GUARD" position and remove key.

If any one of the L.E.D.'s fails to light arrange for an electrician to examine forthwith and report the fact in an appropriate book.

Examination	Subsequent Action
5. Press the push button marked "ON GUARD TEST" on the sensor unit. An adjoining L.E.D. should light for each water disperser in circuit.	If a L.E.D. fails to light arrange for an electrician to examine forthwith and then report the fact in an appropriate book.
6. Check that the sensor unit is positioned at the correct distance from the disperser and the whole barrier at the correct distance from the face in accordance with the diagram attached to the installation.	If positioning is found to be incorrect arrange to re-position in accordance with the installation diagram. Any movement undertaken must be in accordance with Notes for Guidance on Triggered Barrier Installations. Report any movement in an appropriate book.
7. Check that the protective guard is fitted to the outbye end of the disperser.	Report any defects in an appropriate book.
8. Examine for any other apparent defects.	Report any apparent defects found forthwith to the Colliery Mechanical Engineer or mechanic in charge of the mine or to the Colliery Electrical Engineer or the electrician in charge of the mine and then report the fact in an appropriate book.

EXAMINATION 'B'

Examination	Subsequent Action
1. Insert master key (engraved TBM) in sensor unit and:- (i) Turn one position clockwise to "TRANSPORT" position. (ii) Pour hot water over thermocouple elements or immerse thermocouple elements in hot water. A L.E.D. on the sensor unit should light <u>momentarily</u> for each water disperser in circuit. (iii) Return master key to "ON GUARD" position. (iv) Remove key.	If a L.E.D. fails to light report the fact forthwith to the Colliery Electrical Engineer or the Electrician in charge of the mine and then report the fact in an appropriate book.
2. Carry out item 4 of Examination 'A'.	Report any apparent defects immediately to either the Colliery Mechanical Engineer or the mechanic in charge of the mine or to the Colliery Electrical Engineer or the electrician in charge of the mine. Report any such defects in the appropriate book.
3. Inspect and check guards at outbye ends of dispersers.	Report any defects in the appropriate book.
4. Inspect all equipment for physical damage.	Report any defects in the appropriate book.

PLANNED MAINTENANCE (MECHANICAL)

The maintenance is composed of two examinations with recommended frequencies:-

1) Examination 'A' - weekly

2) Examination 'B' - 2 yearly or at greater intervals (not exceeding 26 months) as prescribed by the Manager's Scheme for the Mine.

EXAMINATION 'A'

Examination	Subsequent Action
1. Check that the Nitrogen pressure as indicated by the gauge is in the range 90-110lb p.s.i.	If the pressure is outside this range arrange re-charging. To re-charge, remove the window from in front of the pressure gauge and connect a nitrogen cylinder through pressure reducing gear and Schraeder fitting to the valve below the gauge. THE UNIT MUST NOT BE CHARGED TO A PRESSURE GREATER THAN 110lb psi.
2. Check that the water level is within 75 mm (3 ins) of the top of the filling hole by removing water filling plug on top of the unit at the highest end of the barrier. (The ability to tough the water surface with the tip of the finger indicates the water level is within 75 mm (3ins). Replace filler plug (after topping up if necessary) finger tight.	Top up if necessary using clean water.

Examination	Subsequent Action
3. Check that all suspension equipment is secure and undamaged.	Arrange rectification of any defects noted.
4. Generally check the complete installation for damage, loose bolts and fastenings. In particular check that there are two split pins through each shear screw shroud and that there is no damage to the outer rim of the shroud around the end plate. Never attempt to tighten the nuts on the shear screws.	Arrange rectification of any defects noted.
5. Check that the end guard is fitted to the outbye end of each disperser.	If found defective replace the guard.

EXAMINATION 'B'

1. Remove the complete installation from the mine for proof testing, hydraulic testing and re-furbishing.

PLANNED MAINTENANCE (ELECTRICAL)

The maintenance is composed of three examinations with recommended frequencies:-

1) Examination 'A' - weekly

2) Examination 'B' - 3 monthly

3) Examination 'C' - 2 yearly or at greater intervals (not exceeding 26 months) as prescribed by the Manager's Scheme for the Mine.

EXAMINATION 'A'

Examination	Subsequent Action
1. Insert master key (engraved TBM) in sensor unit. Turn two positions clockwise to "TEST" position. Adjoining L.E.D.'s should light momentarily. (One for each disperser in circuit and one to indicate satisfactory battery condition.)	If no light shows momentarily check for damage to cable or cable glands at both ends of the cable. Any decrease in brilliance of the battery L.E.D. is indicative of a low condition on the battery which should be changed.
2. Press push button marked "ON GUARD TEST" on sensor unit. An adjoining Light Emitting Diode (L.E.D.) should light for each water disperser. in circuit.	If no light shows momentarily check for damage to cable or cable glands at both ends of the cable. Any decrease in brilliance of the battery L.E.D. is indicative of a low condition on the battery which should be changed.
3. Thoroughly examine all electrical equipment externally for physical damage or corrosion.	Arrange rectification of any defects noted.

EXAMINATION 'B'

Examination	Subsequent Action
1. Replace battery in sensor unit. See section 8.3.	Follow instructions in section 8.3 of the Notes of Guidance.
2. Carry out Examination 'A'	See action required.

EXAMINATION 'C'

1. Remove the complete installation from the mine for proof testing and refurbishing.

Short review of the conference of the Working Party on Flammable Dusts held in Luxembourg on 5.11.1981

Kurt REINKE, Versuchsgrube Tremonia, Dortmund

A substantial proportion of the 13 talks given today was devoted to the subject of triggered barriers in line with the decision on the work programme taken by the Working Party on Flammable Dusts at its meeting on 25.11.1980. The fact that as many as four different triggered barrier systems have been described here can be taken as a sign of European diversity. We shall see that this should in no way be considered a drawback since these systems can positively supplement each other.

In the talks given by Mr Rae and Mr Collinson, the triggered barrier developed by the SMRE in the United Kingdom is presented. It is planned to replace the present lightweight stone dust barriers with triggered barriers in the vicinity of production districts. The British system has the indisputable advantage of being exceptionally strong and of not being very dangerous when released accidentally, which we have heard has happened during testing. The barrier is very effective but not very cheap, especially when two detectors and four dispersers have to be used.

The talks given by Mr Browaeys and Mr Goffart describe the operation and testing of the triggered barrier designed by INIEX in Belgium. It is a highly intelligent and original solution to the problem. It will be interesting to observe how this system fares when subjected to further testing in rough practical conditions.

The Bergbau-Versuchsstrecke triggered barrier system presented by Mr Scholl is a mature solution. Unfortunately, the original hopes of finding a "wonder" suppressant powder have not been fulfilled. An explosion in a mine roadway cannot be suppressed with one or two cylinders of suppressant dust as can be done in pipes. This barrier is therefore rather expensive because of the large number of cylinders required. The suppressant powder barrier is ideal for suppressing explosions which build up gradually, when used in conjunction with a fast-reacting ultraviolet detector. As such, it has proved a success when tested both on roadway heading machines, as mentioned by Mr Scholl, and on winning machines Versuchsgrube Tremonia under a research project now approaching completion.

In his talk, Mr Michelis outlined the principles of the Versuchsgrube Tremonia triggered barrier. This system, together with the barrier proposed by INIEX, is without any doubt the cheapest solution to the problem of triggered barriers. Safety, too, should be sold at a reasonable price, and therefore preference should be given to a low-priced system whose there is equality on all other points. The Versuchsgrube Tremonia system has proved no less effective than the other systems in suppressing roadway explosions; its inherent drawbacks (should therefore be accepted). These are, in particular, the large amount of space it takes up compared with the BVS barrier, and its susceptibility to damage. It should be mentioned however that the Versuchsgrube Tremonia barrier also operates like a normal water barrier in the event that it is not triggered properly.

Generally, as far as the problem of triggered barriers is concerned, it should be noted that in the Federal Republic of Germany there is no intention of replacing the water trough barrier system or parts of it with triggered barriers. Where an adequate area of roadway is available, the wide-action water barrier in particular provides such effective protection from explosions that it is scarcely possible to produce anything better for the same price. In the Federal Republic of Germany, therefore, the triggered barrier will only be used where water trough barriers, and especially the wide-action type, do not provide adequate protection from explosions for lack of space or for other reasons.

An interesting example of this is the double explosions mentioned in the talks given by Mr Meerbach and Mr Faber. First, Mr Meerbach gave an introduction to the difficulties encountered in the experimental treatment of this group of problems. Experiments with double explosions, which can definitely occur in practice, as we know, have so far only been feasible in the Versuchsgrube Tremonia. Up to now, it has not been possible to obtain adequate protection from more than one explosions with conventional barriers. The BVS triggered barrier system, which Mr Faber spoke about, provides a solution to this problem. Since this barrier remains intact if it is not triggered by an explosion, it provides suppressant for a secondary explosion. There is an urgent need for this interesting system to be tested in the experiments with double explosions which are to be resumed at Tremonia in the foreseeable future.

Mr Ainsworth raised many problems in his general paper. Some of these, in particular the suppression of explosions occurring in the vicinity of winning machines, have now been solved by research projects. The proposed studies of the principles underlying a coal dust explosion, however, are of general interest. It is to be hoped that this work can soon be tackled on a larger scale in cooperation with all Western European institutes.

We find it rather difficult to understand the aversion of our British colleagues to the water trough barrier, which was evident in this latter talk. As already mentioned, water trough barriers have been in operation in the Federal Republic of Germany for some twenty years now with excellent results. They have also been introduced in other countries, in the meantime. In Mr Jenderek's paper, the design regulations drawn up in the Federal Republic of Germany are described in detail: it is clear that these rules constantly need to be adapted to the state of the art as it becomes more advanced. This work is in fact carried out continuously and will doubtless be brought to a successful conclusion.

Our French colleagues, too, are working more and more with water trough barriers, as we have seen from the talk given by Mr Giltaire and Mr Winter. Apart from a few minor details, the tests they carried out in the Montlaville gallery show the same results as those obtained previously in the Federal Republic of Germany with regard to the installation of troughs, and as set out in the construction specifications mentioned by Mr Jenderek. It is very encouraging to see that physics is not confined by national frontiers and that the same results are obtained in France as in the Federal Republic of Germany. We can only back up the critical comments made by Mr Giltaire on the subject of "neutralization using water".

The talks mentioned so far all dealt with the suppression of coal dust explosions. However, the question of how the development of coal dust explosions can be prevented altogether is at least of equal importance. The papers given by Mr Liberda and Mr Schnier dealt with this group of problems. The very interesting studies carried out by Mr Liberda confirm that it is very difficult, if not impossible, to draw conclusions about dust deposition in roadways from measurements of airborne dust. In our opinion, Mr Liberda's results on the circulation of dust deposits illustrate the inadequate of stone dusting as a means of controlling coal dust explosions. The realization that it is not feasible to use stone dust for neutralization in roadways continual falls of coal dust has led to the demand for neutralization with hygroscopic salts in such roadways in the Federal Republic of Germany. A sad example of the inadequacy of stone-dusting for the prevention of coal dust explosions is the explosion at the Hansa hydromine two years ago.

The use of hygroscopic dust binding faced major difficulties and was rejected by the mining companies in the Federal Republic of Germany to begin with. Mr Schnier's paper, however, shows the extent to which this method has now gained acceptance by the collieries and efficient operation achieved. The modern methods illustrated in the talk have remedied many of the initial, disconcerting aspects of this process, and we still believe that it should be used in other countries of the Community in the interests of mine safety.

I hope I have managed in the short time available to provide you with a short review of the 13 interesting talks we have heard at today's conference, I believe that the conference organized by the Working Party on Flammable Dusts has shown that it is tackling and must continue to tackle, a large number of subjects of exceptional importance to mines safety. Thank you for your attention.

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Sixteen papers were delivered on the following topic groups:

1. Water-trough barriers.
2. Fixed triggered barriers.
3. Mobile triggered barriers.
4. Stone dust barriers.
5. Multiple explosions.
6. Multiple suppression systems.
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